Undermining Futures:

Antarctic Uncertainties in a Risk Society

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March 2021

Tools explicitly developed for polar resource management are a successful way to improve society's ability to combat climate change (IPCC, 2019)

Acknowledgements

I would like to take this opportunity to thank Claire and Mathew Williams for their support. We have had some fantastic conversations, and I am so grateful for all your help. Without your advice and feedback, my dissertation would not be what it is today.

I would also like to thank James Hay, who coached me, and spent many hours being patient with my lack of coding experience. Thank you for the incredible support you have given me over this past year.

Thank you to Adrian and Bob, my two supervisors, who helped me craft my work with insightful views and experience.

Abstract

Future studies and temperature modelling are innovative tools allowing for the development of polar resource management policies and initiatives; however, these tools must be *credible, relevant, and legitimate* to overcome barriers in the science-policy interface. If tools for polar resource management are to be *credible, relevant and legitimate,* then their associated uncertainties must be identified, acknowledged and appropriately communicated.

To date, futures climate modelling for Antarctica has not acknowledged the uncertainties present in the Antarctic's physical and socio-economic elements; nor have scenarios acknowledged the social context that influences how futures are interpreted and accepted. Climate change is a wicked problem, such that there are many uncertainties involved, the risks are high and there is no obvious solution. This dissertation makes the argument that post-truth politics within the context of a risk society intensifies existing uncertainties involved with climate change and together, provides the framework to undermine Antarctic future scenario work and temperature modelling. By acknowledging and referencing uncertainties involved with Antarctic climate modelling and future scenario work, the *credibility, relevance and legitimacy of the science* will be increased.

In an attempt to recognise the diverse range of uncertainties particular to the Antarctic, regional physical and socio-economic elements are evaluated and discussed in this dissertation. This evaluation is displayed in a dashboard of uncertainties for future researchers to utilise, ensuring that Antarctic future scenarios assess and acknowledge different outcomes and paths for physical and socio-economic elements. Model uncertainty is the most crucial physical uncertainty for Antarctica. It is recommended that policy makers acknowledge this uncertainty in order for evidence-based decisions to be made appropriately. Additionally, Antarctic governance is particularly important, as it pervades all socio-economic elements. Researchers should acknowledge the Antarctic Treaty System's future as the most critical of all uncertainties to consider when making future Antarctic scenarios.

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1.	AR4	Assessment Report 4
2.	AR5	Assessment Report 5
3.	AR6	Assessment Report 6
4.	ATCM	Antarctic Treaty Consultative Meetings
5.	ATS	The Antarctic Treaty System
6.	BBNJ	Biodiversity Beyond National Jurisdiction
7.	CBD	Convention on Biological Diversity
8.	CCAMLR	Convention on the Conservation of Antarctic Marine Living Resources
9.	CEMP	CCAMLR Ecosystem Monitoring Program
10.	CMIP3	Coupled Model Intercomparison Project 3
11.	CMIP5	Coupled Model Intercomparison Project 5
12.	CMIP6	Coupled Model Intercomparison Project 6
13.	COMNAP	Council of Managers of National Antarctic Programs
14.	CRELE	Credible, Relevant and Legitimate
15.	DAPPs	Dynamic Adaptive Policy Pathways
16.	EBMs	Energy Balance Models
17.	EMICs	Earth Models of Intermediate Complexity
18.	GCMs	General Circulation Models
19.	GHG	Greenhouse Gas
20.	IAATO	International Association of Antarctica Tour Operators
21.	IAMs	Integrated assessment models
22.	IPCC	International Panel on Climate Change
23.	WMO	Meteorological Organisation
24.	MME	Multimodel Ensembles
25.	NAP	National Antarctic Programmes
26.	RCCs	Rescue Coordination Centres
27.	RCPs	Representative Concentration Pathways
28.	S/N	Signal to Noise Ratios
29.	SCAR	Scientific Committee on Antarctic Research
30.	SPAs	Shared climate Policy Assumptions
31.	SROCC	Special Report on the Ocean and Cryosphere in a Changing Climate

32. SSPs	Shared Socio-economic Pathways
33. UN	United Nation
34. UNCLOS	United Nations Convention on the Law of the Sea
35. UNEP	United Nations Environment Programme

Chapter 1: Climate Uncertainty and a Risk Society

Section 1.1 Introduction

'Climate change refers to a change in the state of the *climate* that can be identified by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer' (IPCC, 2018). Although the climate changes naturally, anthropogenic impacts on the environment are forcing the Earth into a state of global warming, at a rate greater than previously observed. In this dissertation, the term climate change will be referring to climate warming as a result of human forcing.

Climate Change is a wicked problem, as it 'has innumerable causes, is tough to describe, doesn't have a right answer'; and is a global problem, involving a plethora of organisations, governments and individuals[1] (Camillus, 2008). Camillus (2008) explains that a wicked problem originates when there is a situational change. The wicked problem can involve various stakeholders with differing views and opinions on the issue. As more stakeholders are involved more challenges are incurred. The way to tackle a wicked problem is through policy makers 'focusing on action' and 'picking a starting point' (Camillus, 2008).

Politically, for many governments, picking a starting point, and focusing on action is to declare a climate emergency. One thousand nine hundred and three jurisdictions across the globe have declared a climate emergency thus far (Climate Emergency Declaration, 2021). New Zealand Climate Change Minister James Shaw described the motion as a 'clear statement of intent to tackle the crisis' (Morton, 2020). The Minister later explained that policy would follow the 'gesture' (Morton, 2020) to mitigate emissions to lower the rate of warming. The term *emergency* implies urgency, clearly stating the governments stance towards climate change. It places the topic on the agenda, raising public attention and awareness of the issue (Willis, 2020). However, it is also a political manoeuvre, where governments may be seen as making progress towards solving climate change, even when nothing has been achieved.

[1] Camillus (2008) collates various papers discussing the definitions and challenges to a wicked problem. Wicked does not refer to a degree of difficulty, rather it denotes an issue or problem that is not solvable via traditional policy methods or approaches (Horst & Melvin, 1973).

By declaring a climate emergency, the government has therefore picked a starting point, and as Camillus notes the next step is for policy makers to focus on action. One way of doing this is future scenario making and temperature modelling. These are tools that allow insight into how the globe or region will respond to climate change, again raising public awareness of the issue, communicating the issue, and facilitating adaptational policy change (Houghton et al., 1997).

However, communicating the science is not always simple. There are several boundaries across the science policy interface, 'acting as barriers to communication and collaboration' (Cash et al., 2002). To overcome these barriers, Cash et al. (2002, 2003) propose the CRELE framework; whereby information must be *credible, relevant and legitimate*. The credibility of information refers to its trustworthiness; a trait commonly focused upon within climate science (Cash et al., 2002). Relevance deals with how commonly connected the topic is to policy makers priorities. Legitimacy is how impartial the information is to different viewpoints and stakeholders. As previously mentioned, climate models and future scenario making can be used as tools, bridging the science policy interface. However, these tools will only ever break through this interface's boundaries if they are proved credible, relevant, and legitimate.

Understanding the physical uncertainties helps quantify how reliable climate models are and how uncertainties manifest in future Antarctic temperature change predictions. Combining physical uncertainties with regional socio-economic uncertainties provides a holistic view of regional pressures, thus considering all relevant stakeholders, thereby providing legitimacy to climate models and future scenarios.

This dissertation will concentrate on identifying and understanding physical and socio-economic uncertainties in Antarctica to fill the gap in literature that currently exists in this space. Although various Antarctic future scenarios have been constructed (Liggett et al., 2017; Rintoul et al., 2018), these do not refer to the region's uncertainties.

By looking at climate change within a societal framework and acknowledging that it is a wicked problem, it can be ascertained that physical and socio-economic uncertainties constrain the accuracy of future scenario work and climate modelling. This dissertation will answer the question:

How do the physical uncertainties associated with Antarctic climate model projections and Antarctic socio-economic uncertainties combine to question the credibility, relevance, and legitimacy of Antarctic scenarios?

Beck's (1992) theory of a risk society explains how modernisation and industrialisation has framed how society views and reacts to risk. The notion is that modernization amplifies existing insecurities forcing society to view problems with increased scepticism. Post-truth politics as an element of modern society further complicates the already complex issue of climate change (Beck, 1992).

In this dissertation, climate change will be discussed within the context of a risk society. It will show that the social construct of a risk society intensifies uncertainties, leading people to question the credibility, relevance and legitimacy of information within the science policy interface.

The definition of uncertainties in context with risk will be defined by using existing frameworks (O'Neill, 2017; Frame, 2019; Frame 2020) to compile and then analyse a list of socio-economic elements particular to the Antarctic. Uncertainties will then be identified from each element and the most significant uncertainty will be identified to aid in future studies.

Note:
Antarctica refers to the continent within the Antarctic; any region of land or ocean below 60° South, or the Antarctic convergence (National Geographic Society, 2012). This dissertation will be referring to temperature projections for the Antarctic, where the appropriate calculations reflect anything below 60° South. Furthermore, socio-economic elements of both the continent of Antarctica and the Antarctic will be discussed.

Section 1.2 Background

1.2.1 Risk Society

The social theory of risk society is a significant part of this dissertation. The following section provides background on risk society, including aspects of modernity, and its relevance to climate change.

Risk is not the detrimental event that will occur as a result of an action, but rather, risk is the anticipation of that event (Beck, 2006). As soon as risk becomes real, Beck explains that it becomes a catastrophe (Beck, 2006). Without planning and foresight work, risks do not exist. It is the visualisation of risks that lead to actions of mediation.

Within his publication, risk society: Towards a New Modernity Beck discusses the shift to modernity and with this shift, he describes two phases in which, when dealing with unanticipated consequences of technological development, societies evaluate potential risks and that, in turn, negatively impacts their perception of scientific and political institutions (Beck, 1992; Wimmer & Quandt, 2006).

In acknowledging Beck's theory, it pays to highlight that critics have communicated issues with a 'risk society' and its ability to be valid when placed in certain contexts. Ormrod, (2013) states that 'the most discussion has centred on whether Beck's understanding of risk is a realist or constructionist one' (Ormrod, 2013, p. 728). Furthermore, Mythen & Walklate (2006) build on this statement by explaining that 'in particular, the conflation of risk and uncertainty weakens the purchase of Beck's thesis, leading him to entertain unrealistic ideas about the redistribution of social problems' (Mythen & Walklate, 2006, p. 393). However, in response to these critics, neither discount Beck's risk society as a valuable concept and instead proposes that it is inappropriate for certain contexts. This dissertation supports the argument made by Bulkeley, (2001) whereby the context of climate change fits the theory of a risk society perfectly. 'The unbound nature of climate risk has profound implications for society, rendering environmental regulation based on national boarders and future predictability impotent, and leading to new conflicts which stretch social relations over space and time' (Bulkeley, 2001, p.434). The ideas presented by Beck were released the same year as the Chernobyl nuclear disaster. The Chernobyl incident encapsulated Beck's proposed risk society's notions in an environmental context.

The risks associated with climate change are so profound they are difficult for some to comprehend. The problem is complex and global and may not be solved through conventional means, with the consequences almost unrealistic. The view of climate change in context with Beck's theory is thus dystopian 'in this respect, the risk-society perspective serves as both a timely political wake-up call and a harbinger for the future' (Mythen & Walklate, 2006, p. 393). For this reason, criticism of Beck's risk society being constructionist is invalid when viewed with the dystopian nature of the climate emergency. Therefore, a risk society can explain the social response to the risks of climate change, given its unrealistic nature.

Climate change fits the exact profile of an unintended consequence of modernity. Technological advances in industrialisation, consumerism, and transport, are all human developments that have made life more comfortable. However, these developments have had unintended consequences that have begun to impact our environment negatively.

When regarding the catastrophe of global climate change, Beck refers to a significant concept; *Metamorphosis of the World.* This notion describes global change occurring due to human actions, with multiple defining features (Beck, 2015). The world is metamorphosing, with modernisation occurring due to industrialisation. The 'goods' that result from modernisation also incur several unintended 'bads' (Beck, 2015). In reviewing Beck's theories, Chou confirmed that the effects of climate change are unanticipated (Chou, 2018).

Climate change is complex, involving many uncertainties. Due to the complexity, the theory of risk society results in society viewing it as too challenging to solve or some may deny its legitimacy altogether. Figure 1 depicts the concept of a risk society, using climate change as an example.

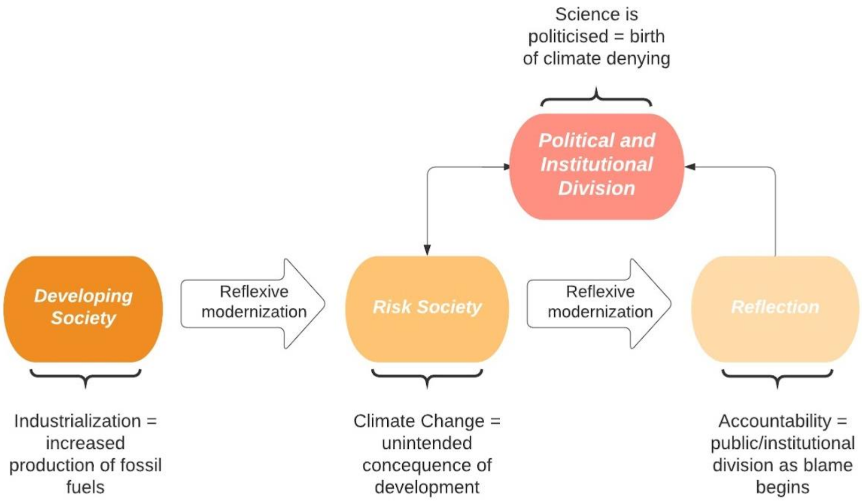

Figure 1 Flow diagram, describing the dynamics of a risk society, with climate change as an example

The unintended 'bads' have led to what has been described as the *age of side effects* where the public constantly question authoritative figures or institutions (Beck, 2015). Therefore, public mistrust within a risk society is intensified by the uncertainties within climate change science and the wide gaps of knowledge in the field.

Mythen (2004) explains that the definition of 'risk' has evolved with time. The concepts of 'risk' and 'uncertainty' have primarily been separated, with the outcomes of risk known, whilst uncertainty implies unknown consequences. However, in modern-day science, risk involves several uncertainties, which creates an issue when quantifying and understanding risks. The definitions of risk and uncertainty will be further discussed in the *Uncertainty is Futures* section (1.3.2).

Scientists and other experts use modelling to evaluate global climate change risks. Understanding the societal, political, and environmental risks resulting from climate change allows for management plans or restoration projects to minimise this risk. Today, it is accepted that all risks involve uncertainty and probability; that is, potential dangers or hazards that may result in the future. This uncertainty and probability will always be present when predicting future changes (Mythen, 2004). It is understandable then that minimising the uncertainties within predictions would lead to a better understanding of society's potential risks.

Figure 2 depicts a risk society world, where similar processes to Figure 1 are occurring; however, climate science is present, minimising uncertainties, leading to improvements in environmental risk management.

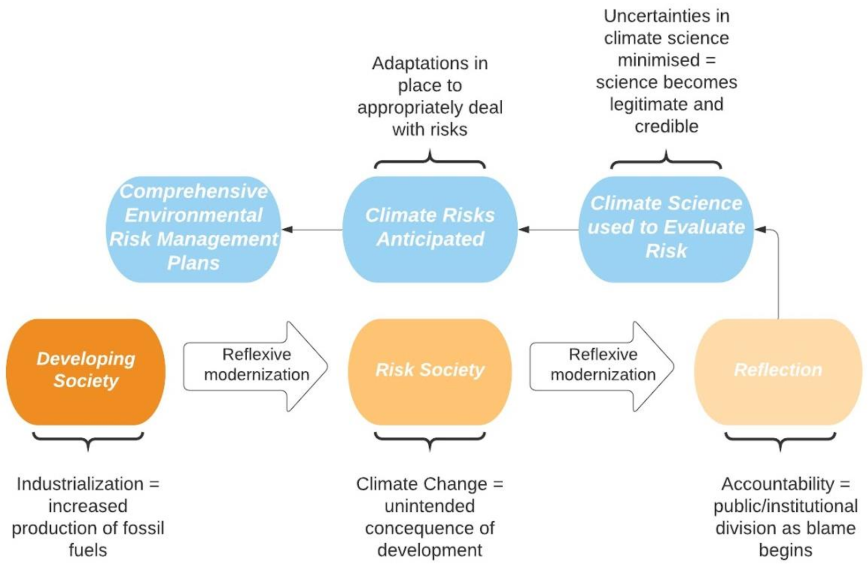

Figure 2 Flow diagram, describing the dynamics of a risk society, with climate change risks anticipated, as a result of the acceptance of climate science

Science must utilise tools, like climate models, to communicate risks to policy advisors and facilitate public outreach. However, without quantifying and understanding the uncertainties within these climate science tools, the results lack legitimacy. The credibility of results is further challenged within a world of post-truth politics.

The post-truth politics world is one where facts have less influence on public opinion due to the intervention of personable politicians and selective agendas. Most commonly, Donald Trump is a face for post-truth politics, with supporters following and believing his statements, even without any factual basis (Spoelstra, 2020). 'The term 'post-truth' suggests that the public, or the electorate, shows little interest in 'the truth', instead casting their votes for the candidate who manages to appeal to their emotions and beliefs' (Spoelstra, 2020, p.757). However, post-truth must be separated from that of lying. Post-truth 'doesn't simply deny or question certain facts, but it aims to undermine the theoretical infrastructure that makes it possible to have a conversation about the truth' (Bufacchi, 2020).

As a wicked problem in a risk society, climate change already incurs doubt within its factual evidence. Society does not trust institutions and questions the credibility of science. Furthermore, with post-truth acting to *undermine* the basis of an issue or subject, any uncertainties within the evidence or data to support a theory can potentially be used as political tools to manipulate how it will be accepted by society.

1.2.2 Climate Models

<u>What are Climate Models</u>

A portion of research on uncertainties in the Antarctic focuses on climate modelling. The following section will provide background on and explain how climate models make temperature projections.

Climate models are tools to predict changes in the climate system (Gettelman & Rood, 2016). Used for public outreach and policy communication, parameters within the climate system are forecast on different time and spatial scales. Models can also be used to understand the climate system and how it interacts with socio-economic elements. Decision makers and policymakers use climate models for insight into potential future risks that may impact the globe due to a changing climate. These changes can occur globally and regionally, with different climate models forcing predictions accordingly (Gettelman & Rood, 2016). The interpretation of a model's output can communicate urgent changes required to decrease anthropogenic emissions (Wilby & Dessai, 2010).

There are many climate models, with a plethora used by the International Panel on Climate Changes (IPCC) in their climate Assessment Reports (Houghton et al., 1997; IPCC, 2014, 2019, 2021). These different models have individual strengths and weaknesses, with some models suited to particular tasks more than others. This section discusses climate model's background, detailing the different types of models and their strengths and weaknesses in different contexts, with specific mention of climate models used by the IPCC and policy communication.

The creation of climate models involves three stages:

1. *Physical laws of nature, such as energy and momentum, must be represented as mathematical expressions;*
2. *Computers and software express these equations; and*
3. *Models are further built to encapsulate natural processes* (Kattsov et al., 2013).

Simple and Complex Models

There are simple and complex climate models. The equations involved within simulating the Earth's climate can either be minimal or expansive, depending on the level of output accuracy and the number of parameters involved within the calculations. A model with a small number of equations and variables is termed 'simple', whilst a model combining larger amounts of Earth system parameters is 'complex' (Gettelman & Rood, 2016). Simple climate models are computationally cheaper and faster to run, requiring fewer resources. These models are suitable for projecting futures involving a singular parameter and often do not involve many climate system complexities. Conversely, complex models are usually more expensive and take more time and effort to run. Generally, with increasing parameters and resolutions, there will be an increase in model complexity (Mcguffie & Henderson-Sellers, 2014).

Simple and complex models have their advantages and disadvantages; therefore, some models are preferred over others depending on the research focus. International climate reports utilise both simple and complex models for various reasons and predictions (Houghton et al., 1997; IPCC, 2014, 2019, 2021). Projected parameters and regions define the type of model being used (Mcguffie & Henderson-sellers, 2014).

The science-policy interface uses models as tools for science communication and policy development (Houghton et al., 1997). Public perception significantly alters how decision-makers receive new scientific information (Lemos & Rood, 2010). Easily interpreted and inexpensive, simple models can be a tool to bridge the gap between science and policy, with non-climate scientists understanding the outputs (Houghton et al., 1997).

Types of models

Either complicated or straightforward, climate models are organised into various categories.

Energy Balance Models (EBMs) are examples of a simple climate model (Mcguffie & Henderson-sellers, 2014; North. R & Kim, 2017). They focus on a single parameter within the climate system, and help understand how physical processes in the climate system might function.

Earth Models of Intermediate Complexity (EMICs) act as the middle position between simple and complex models. These models forecast changes within the climate that involve more than one parameter, therefore advancing their level of complexity (Alexeev et al., 2002). The predictions made by EMICs are most commonly made for large regions across the globe, aiming to detail multiple climate system dynamics (Alexeev et al., 2002).

General Circulation Models (GCMs) are the most complex atmospheric climate models that forecast climate change globally. (North. R & Kim, 2017). They involve high levels of climate interactions, and represent large numbers of physical processes mathematically, inputting as many parameters of the climate system as possible. Due to their complexity, GCMs are expensive and time-intensive. They are the climate model most suited to forecasting global climate change. (Rummukainen, 2010).

Integrated Assessment Models

Integrated assessment models (IAMs) combine different climate parameters with different parts of the Earth system. They determine how humans interact with the climate and how anthropogenic actions may influence it (Gettelman & Rood, 2016). IAM's model anthropogenic greenhouse gas (GHG) emission levels and climatic parameters alongside each other. Similar to simple models, IAMs bridge the gap between science and policy. IAMs allow the anthropogenic effect on climate to be quantified into something relevant to policymakers, placing environmental impacts in context, socially and politically (Pindyck, 2017).

Multimodel Ensembles

The outputs of multiple climate models can be combined to create Multimodel Ensembles (MME) (Samouly et al., 2018). The combination of initial conditions, parameters, and model uncertainties produce comprehensive datasets (Tebaldi & Knutti, 2007) that are generally more reliable than singular climate models. MMEs also quantify uncertainty in projections rather than just being used in simulations of future climate. Evaluation of MMEs determines the GHG emission effects on the climate. Upon analysis, the mean of an MME is the most accurate representation of future climate, whilst the MME spread is the uncertainty in that prediction (Christiansen, 2020).

International Panel on Climate Change

The International Panel on Climate Change (IPCC) was formed in 1988 by the World Meteorological Organisation (WMO) and the United Nations Environment Programme (UNEP) (International Panel on Climate Change, n.d.). Volunteer IPCC scientists and experts from institutions worldwide contribute to the research and work done within the reports and papers. These are later evaluated by multiple editors and governments, resulting in non-biased, factual information about climate change (International Panel on Climate Change, n.d.). The IPCC collates climate models from various international scientists and groups and uses them in their Assessment Reports. The scientific question determines the model used.

Coupled Model Intercomparison Project Modelling

The Coupled Model Intercomparison Project 3 (CMIP3) was used and evaluated in the IPCC's Assessment Report 4 (AR4), released in 2007 (Kattsov et al., 2013). The IPCC uses these evaluations of CMIP3 to compare them with the more developed CMIP5, displaying how climate modelling had improved over the seven years before the publication of Assessment Report 5 (AR5) in 2014. Assessment Report 6 was due for release in 2021, but has been delayed, due to the COVID-19 pandemic, with the final synthesis report now due for publication in 2022. Whilst the report is yet to be released, a subset of the CMIP6 models has been released. This dissertation will subsequently use a portion of this CMIP6 data.

Improvements to a model's ability to predict future conditions and simulate Earth processes are crucial to its reliability. If models forecast highly incorrect projections, then the adaptational and mitigation policies will not effectively combat climate change. Similarly, for environmental adaptations to be successful, regional climate models must project future conditions accurately.

CMIP6 focuses on solving climate projection questions that arose from CMIP5. Given CMIP6's improvements to climate forcing, results would be more accurate and up to date than the CMIP5 forecasts.

Section 1.3 Literature review

1.3.1 Antarctic Futures

Future Scenario making is an integral part of policy work. Dependent on the specific research aims, different methodology creates a set of futures pertinent to the study's objective. The framework applied to future scenarios' design can differ, depending on the specified region's environmental, social, and political contexts. The following section aims to review past futures work and analyse different methods used, identifying the best framework for creating Antarctic futures. This dissertation will identify the most significant socio-economic elements contributing to the Antarctic's future by examining previous literature related to global futures, regional futures and Antarctic futures scenario frameworks. Chapter 3 will analyse these Antarctic socio-economic elements for their uncertainties.

Scenario Framework

There are challenges associated with making political and social adaptations to decrease the effects of climate change (Ebi, Kram, et al., 2014). To accurately observe how climate affects socio-economic parameters, it is essential for policy advice to use climate modelling alongside political and social elements in global and regional futures work.

The IPCC created four RCPs in 2014, each projecting a potential pathway for the globe by 2100 (Moss et al., 2010). Each pathway involves emitted greenhouse gases defined by their radiative forcing and trajectory (Ebi et al., 2014). Shared Socio-economic Pathways (SSPs) and Shared climate Policy Assumptions (SPAs) are the political and social equivalents to 'Representative Concentration Pathways (RCPs), together combining to create the SSP, SPA and RCP scenario matrix' (Ebi, Kram, et al., 2014; Ebi, Hallegatte, et al., 2014). The matrix provides an understanding of how one parameter may affect another. Over time the descriptions of SSPs, RCPs and SPAs have changed to result in more accurate futures work (O'Neill et al., 2014).

Global Futures

O'Neill et al. (2017) further develop his original 2014 work by discussing the use of SSPs in developing long term global scenarios and their role in climate change analysis. There are five SSP scenarios, each with unique conditions, defining differences in societal change

(O'Neill et al., 2017). An in-depth summary of each narrative and its associated climate, social, and political parameters are summarised in Table 1. SSP scenarios can be flexible, with narratives containing global scenario parameters, along with parameters that may differ for regional scenarios under the same narrative.

O'Neill et al. (2017) propose a set of socio-economic elements that provide adaptation and mitigation challenges (Table 2). These are extremely helpful to researchers, as it allows the study into each socio-economic parameter, with analysis on their ability to shape future global change. With regional elements commonly being area-specific versions of what is occurring globally, O'Neill et al. (2017) global elements provide a benchmark for creating lists of socio-economic elements specific to a region.

Regional Futures

Global futures and policy advice commonly uses the matrix framework. However, there is an increasing need for scenario scaling and assessing the SSP's and evaluating their usage within a regional setting for regional futures (Ebi, Hallegatte, et al., 2014).

Beck thought it was clear that geographically, environmental consequences had a flow-on effect, where global risks can be felt locally (Mythen, 2004). In the example of climate change, the global temperature rise has local risks of rising seas and unpredictable weather events. These consequences are heightening humans awareness of the issue and their impact on the environment. However, as Frame et al. (2018) notes, local conditions can differ significantly from those globally, creating what is described as 'mini worlds' (Frame et al., 2018). Downsizing global conditions to mimic a country or region is a significant and potentially incorrect assumption, as local parameters influence a region greatly.

As Antarctic socio, political and environmental parameters differ significantly from the rest of the globe, these must be acknowledged when discussing the future of the Antarctic.
By identifying the conditions that specifically impact regions rather than downscaling global conditions, futures scenarios will be more accurate, region-specific and targeted, making them more appealing to local government and decision-makers (Frame et al., 2018).

Antarctic Futures

In 2019, the IPCC published the *Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC)* (Pörtner et al., 2019). The report discusses climate projections for the ocean and cryosphere, providing outlooks on the Antarctic's future in a changing climate. As stated within the SROCC, 'The polar regions will be profoundly different in the future compared with today, and the degree and nature of that difference will depend strongly on the rate and magnitude of global climate change. This will challenge adaptation responses regionally and worldwide' (Pörtner et al., 2019, p.206). The IPCC recognises the Antarctic's future impact, not just environmentally but socially and politically. In direct relevance to Antarctic foresight and Antarctic temperature modelling, the IPCC states that tools explicitly developed for polar resource management are a successful way to improve a society's ability to combat climate change. Examples of these explicit polar management tools are climate models and Antarctic futures scenarios that incorporate explicit regional conditions and socio-economic elements. The differences in socio-economic elements between the Antarctic and the rest of the globe may result in different outcomes when regionally downscaled. Antarctic futures need to 'capture relevant perspectives and uncertainties' (O'Neill et al., 2020, p.1080). Therefore, the Antarctic's political, social and environmental elements must be thoroughly researched and evaluated. The SROCC stresses the need for more work to be completed within the Antarctic climate change sector, specifically in areas concerned with linking future Antarctic climate with government and society (Pörtner et al., 2019).

This dissertation will support the request by the SROCC to increase research into the Antarctic sector by building upon existing futures frameworks and providing insight into the uncertainties involved in Antarctic futures work. This acknowledgement of uncertainties within foresight work ensures more credible, relevant and legitimate Antarctic futures. The work will act as a tool for researchers, governments and institutions, increasing their ability to plan and create legislation that can minimise regional and global emission levels.

Existing Antarctic futures each have their strengths and weaknesses. Rintoul et al. (2018) present two potential future scenarios for the Antarctic, set in 2070. The first scenario illustrates unregulated emission levels and an ineffective policy environment. In the second future, policy decisions vastly decrease emission levels. The climactic futures were coupled with past societal trends, developing two future Antarctic outcomes that consisted of a mixture of both the societal and climate aspects of narrative making.

Coupling socio-economic trends with Antarctic climate patterns develops Antarctic futures that are cross-disciplinary. Rintoul et al. (2018) demonstrate that the Antarctic's future will be negatively impacted unless political action is taken to reduce emission levels. However, by assuming the Antarctic's future could go one of two ways, Rintoul et al. (2018) ignore the uncertainties within socio-economic and climatic parameters, resulting in the two future scenarios not being credible.

Rintoul et al. (2018) displayed how inaction leads to Antarctic destruction; however, did not provide breakthrough scientific discoveries or results. The two futures acted more as public outreach rather than providing new information.

Liggett et al. (2017) analyse the major parameters driving future change in the Antarctic and provide an alternative view of the continent's future. By analysing Antarctic challenges and meticulously evaluating socio-economic elements, Liggett et al. provide credibility, relevance and legitimacy to their futures.

Based on previous literature, Liggett et al. (2017) state that the parameters most likely to impact the future of the Antarctic are:

'global environmental and socio-economic developments; Antarctic governance; Antarctic research, including national Antarctic programme operations; and Antarctic tourism' (Liggett et al., 2017, p.459).

Liggett et al. (2017) explained that the four Antarctic future scenarios created were to 'stimulate further discussion, rather than provide predictions' (Liggett et al., 2017, p.474). This point is similar to Rintoul et al. (2018); however, the creation of the four futures by Liggett et al. (2017) provides a comprehensive overview of a range of potential scenarios rather than the creation of just two unrealistic futures. There is a need for more advanced and insightful tools, such as future scenario work, to aid in Antarctic adaptational planning (Pörtner et al., 2019).

Frame (2019) provides a structure for researches creating Antarctic futures, aligning Antarctic futures ‘within the broader scope of future studies’ (Frame, 2019, p.236). The framework devised by Frame splits future studies into three categories: *Extrapolatory, Back-Casting and Exploratory*.

Extrapolatory futures use current trends and physical data to extrapolate future scenarios. *Back-Casting* involves viewing the future as ‘utopian’ or ‘dystopian’ and creates worst and best-case scenarios. An example of Back-Casting is the two Antarctic futures by Rintoul et al. (2018). *Exploratory* studies combine both the Extrapolatory and Back-Casting methodologies, using trends to create realistic futures. However, Exploratory studies employ decision making to infer whether a future may deviate from current trends. These futures involve a variety of stakeholders, all with different and sometimes opposing views.

The most complex and cross-disciplinary futures making method is *Integral Futures* which involves critical theory and cultural studies. Integral future making moves beyond using traditional tools of examining trends and works to understand the cultural and societal complexities that may lead to uncertain and volatile futures (Frame, 2019).

Frame (2020) builds upon previous work (Frame, 2019), by highlighting the importance socio-economic elements have on the Antarctic’s future. There are complexities involved within the interactions of the Antarctic’s climate, society and politics, and information between these parameters must be communicated for results to be policy-relevant (Frame, 2020b).

Future scenarios need to ‘improve applicability to regional and local scales’ (O’Neill et al., 2020, p.1079). The political system in the Antarctic is precarious as it does not involve a single government but relies on treaties and consensus. Furthermore, the Antarctic is subsequently unique with its processes of environmental protection. Therefore, new Antarctic future scenarios need to analyse how political changes or uncertainty may impact the Antarctic’s future (Frame, 2020).

Furthermore, ‘a continuous re-evaluation of the current range of uncertainties in SSPs, RCPs and their combinations’ is required when making global or regional futures (O’Neill et al., 2020, p.1080). Analysing Uncertainties within the modelling, climate, social, political, and economic spheres provides for the diversity and different perspectives O'Neill et al. calls for. (O'Neill et al., 2020).

An Antarctic integrated futures proposal, suggested by Frame (2020), builds upon research by O'Neill et al. (2014, 2017), resulting in a framework for future studies centred around the Antarctic continent.

As previously discussed within this section, O'Neill et al. (2017) created a list of critical elements contributing to the globe's political, environmental and social future. These parameters were listed as nine categories with 24 physical, social and geopolitical elements (Table 2). O'Neill et al. (2017) compiled the elements, proposing that they act as the basis for global climate scenarios.
Within his research note *Towards an Antarctic scenarios dashboard* Frame (2020a) builds on his previous work (Frame, 2020), providing a comprehensive dashboard of 7 categories, with 17 associated elements, all specifically impacting future Antarctic Scenarios (derived from O'Neill et al. (2017) set of global scenario elements). Each element has indicators that act as 'quantifiable, outcome-based statements to measure the extent to which goals or objectives are met' (Frame, 2020a, p.462).

The seven categories that Frame (2020a) derived from O'Neill et al. (2017) are as follows:

Direct Human Impact; Economic Impact; Ecological and Environmental Processes; Resources exploitation; Institutions and Governance; Technological Development; and Broader societal factors.

These seven categories reflect specific human activities in the Antarctic. Frame (2020a) explains that the categories include various relevant topics, merging the interests of individuals with significance to the Antarctic's future. A more detailed copy of Frames (2020a) elements and indicators is attached as a dashboard (Table 3). Using this dashboard of elements allows researchers to create future Antarctic scenarios with an integrated approach allowing societal, political and environmental factors to work cohesively together, with the RCPs, SSPs and SPAs all combining to create sets of scenarios. (Frame, 2020a).

O'Neill et al. (2020) explain that by increasing the inclusiveness of scenarios, futures are more applicable to groups and individuals from different organisations and sectors, increasing their relevance to different 'communities and cultures' (O'Neill et al., 2020, p.1080).
Literature acknowledges that foresight work and temperature modelling are tools that work closely together to predict environmental risk. No Antarctic futures work to date has used the approach that integrates climate modelling with social and political factors, as Frame suggests (2020).

This dissertation will identify the uncertainties within the Antarctic socio-economic space, so new future scenarios can be made that acknowledge and explore these uncertainties and how they may affect the future of the continent.

1.3.2 Uncertainty in Futures

Predicting the future, globally or regionally, involves high levels of uncertainties. Uncertainties can be in the empirical modelling portion of a region and within the system's socio-economic elements. Combining physical uncertainties with Antarctic socio-economic uncertainties result in more credible, relevant, or legitimate tools for polar resource management.
The following section will highlight the different sources of physical and socio-economic uncertainties in an Antarctic context. Various definitions for uncertainties will be discussed in context with risk, as uncertainties can have different meanings depending on their context.

<u>Model Uncertainties</u>
Uncertainties within climate model predictions arise from three different sources:
Model Uncertainty, Scenario Uncertainty, and Natural Climate Variability.

Uncertainties constrain climate models' reliability. These uncertainties are essential within the climate science sphere and are important when dealing with the science-policy interface. Uncertainty within climate models reduces the accuracy of the output itself and decreases the public's ability to understand and receive the message being forecast (Lemos & Rood, 2010). Decreasing the sources of uncertainty within climate models would increase their accuracy, resulting in more reliable information for future scenarios. There will never be 'perfect' models, with unknowns always present within the climate system (Lemos & Rood, 2010).

However, the more sources of uncertainty that can be minimised and acknowledged within climate models, the more credible, reliable and legitimate climate modelling will be.
The three types of climate model uncertainties come from computational errors, unknowns within the Earth system and their processes, and uncertainties involved when predicting future scenarios; these will be described in the following paragraphs and will later be referenced in Chapter 2.

The climate system has a certain amount of *Internal Variability* (also known as *Natural Variability)* associated with any projections. Climate model predictions are forced in a chaotic system, where the natural variability is a given. Hawkins and Sutton (2009) explain natural variability as fluctuations that occur in response to an absence of radiative forcing at a given time. Natural climate variability can disguise or intensify anthropogenic changes in the climate and potentially reverse the long-term trends of human-forced climate change. Therefore, those tasked with making decisions around adapting to a warming world need to recognise and understand these fluctuations (Hawkins & Sutton, 2011).

Model Uncertainty relates to any unknowns associated with the model itself. Depending on the model's structure, a specific radiative forcing response will be different (Hawkins & Sutton, 2009). Model uncertainty can also be due to the poor representations of earth system processes and their uncertainties in their paramatisation.

Scenario Uncertainty is the final type of uncertainty associated with modelling future projections. The model outputs rely heavily on its inputs. Depending on how these inputs change, the overall result will differ. A future projection will never be entirely accurate, with the scenario chosen to input into a climate model will always have uncertainties associated with it (Hawkins & Sutton, 2009).

The three sources of uncertainty mentioned above take on different levels of importance over different timescales and different regions (Hawkins and Sutton, 2009). The Antarctic will have different types and levels of uncertainty due to specific climatic processes active in the polar regions, such as polar amplification, but nowhere else on the globe.

Quantifying Uncertainties in Models

When Hawkins and Sutton plotted the three sources of uncertainty using CMIP3 data for the globe, they found that the three sources of uncertainty took precedence depending on the lead time and the prediction's regional scale (Hawkins and Sutton 2009). In either shorter, or longer projection times (decadal or multi-decadal), *model uncertainty* is dominant. However, *internal variability* plays a vital role in shorter projection times and smaller spatial scales. *Scenario uncertainty* is more important on larger time scales (Hawkins & Sutton, 2009).

Although Hawkins & Sutton (2009) modelling was completed using CMIP3 data, the paper's ideas remain applicable to modern-day climate projections.

As observed in Figure 3, Hawkins and Sutton (2009) modelled the fractional uncertainty at global and regional scales, determining what sources of uncertainty took precedence at particular times. Depending on the region projected, there were differences in uncertainty and what source of uncertainty dominated. Fractional uncertainty projections are beneficial for adaptational policymaking. Futures makers can evaluate these uncertainties to make legitimate future scenarios.

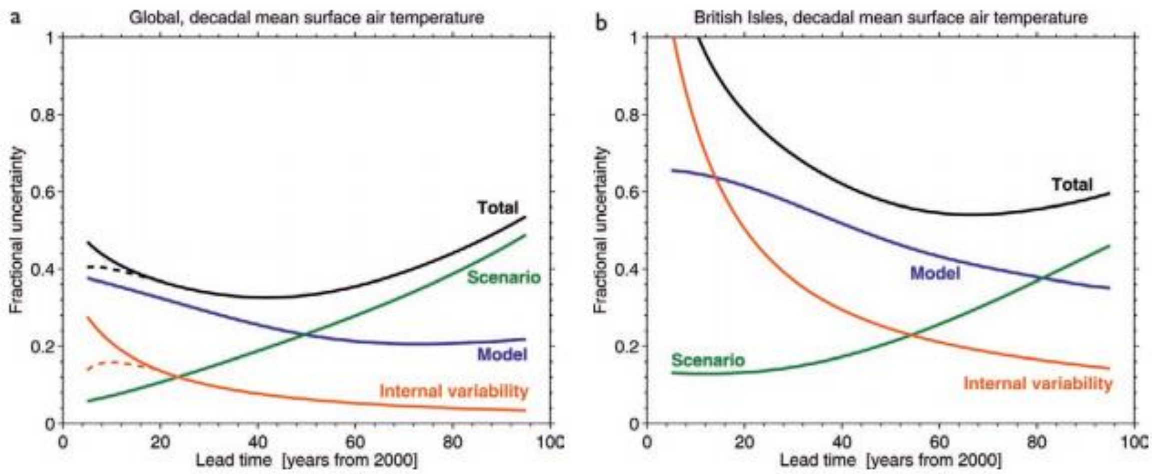

Figure 3 Fractional Uncertainty for Model Uncertainty, Scenario Uncertainty and Internal Variability for the Globe and the British Isles using CMIP3. Copied from Hawkins and Sutton (2009)

Figure 3 from Hawkins and Sutton (2009) shows the three sources of fractional uncertainty for both the globe and the British Isles. The significant observed differences between the fractional uncertainty for the globe and the British Isles are that the model and scenario uncertainty remain the most dominant uncertainty forces. However, as previously mentioned,

natural variability is more important throughout the entire projection for the British Isles and most important during the first 60 years of projections.
The importance of internal variability of the climate is far smaller in the projection for the globe, comparatively—the total overall uncertainty between projections increases on the smaller spatial scale. Model uncertainty is more significant within the smaller spatial scale, whilst scenario uncertainty remains reasonably similar.

<u>Importance of Narrowing Model Uncertainties</u>
Wilby and Dessai (2010) pose the question:

How can environmental adaptation's societal benefits be recognised if all models predicting change include uncertainties?

Uncertainties within climate models will affect the outcome of any given parameter chosen and will be intensified if used in conjunction with socio-economic and political models in IAMs (Schneider & Mastrandrea, 2009). Hawkins and Sutton (2009, 2011) effectively address the ability to minimise climate model uncertainties explaining that model uncertainty can be minimized. Internal variability is a measurement of the natural variability and therefore is not reducible. It is challenging to minimise scenario uncertainty (Hawkins and Sutton, 2009).

To further analyse uncertainty on a regional scale, Hawkins and Sutton (2009) modelled the continental signal to noise (S/N) ratios. The S/N is attached as Figure 4—the more considerable the S/N, the smaller the fractional uncertainty. Hawkins and Sutton (2009) explain the high uncertainty involved with high latitude climate feedbacks, resulting in Greenland exhibiting a much lower S/N ratio than the globe.

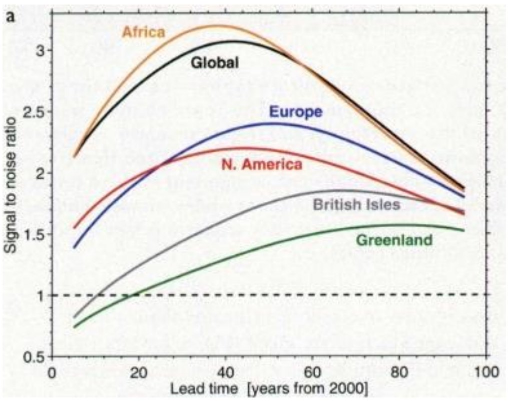

Figure 4 Signal to noise ratio of surface air temperatures at different regions, copied from Hawkins and Sutton (2009)

The low S/N for Greenland is representative of high amounts of fractional uncertainty.
Because it is a polar region, it is likely to exhibit higher than average model uncertainty and natural

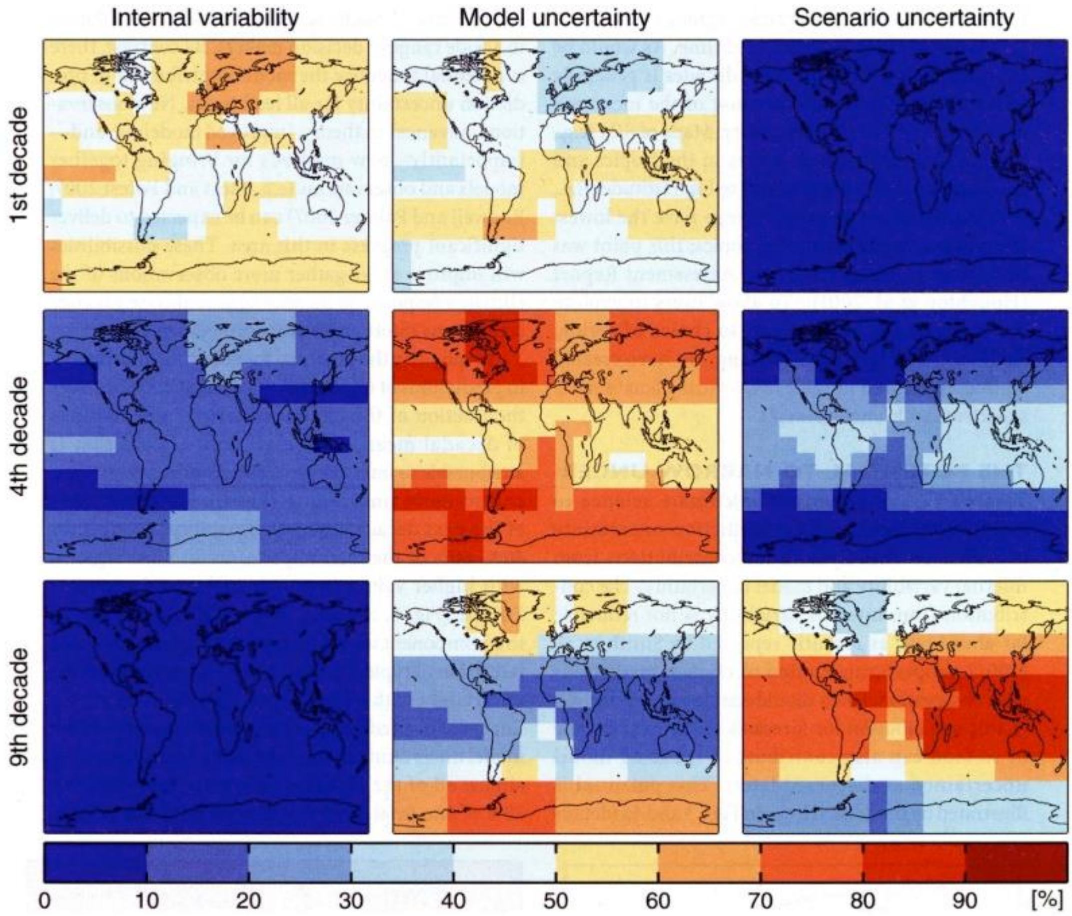

Figure 5 Visual representation of the importance of different sources of uncertainties at different time scales and latitudes, copied from Hawkins and Sutton (2009)

variability due to poor representations of climate processes and unique climate feedbacks systems.

Hawkins and Sutton (2009) argue that model uncertainty has clear maximums in high latitudes, which could be explained by the uncertainty involved with projecting the climate feedback loops within these regions. In longer decadal periods, model uncertainty accounts for the most significant fraction of variance. From Hawkins and Sutton (2009), a global map of the sources of uncertainty at different latitudes is attached as Figure 5.

Hawkins and Sutton (2009) state that the most important source of uncertainty over the next decade or so in climate projections is model uncertainty. This is especially true in polar regions as there are unique climate processes that may not be represented correctly. Furthermore, model uncertainty is the most important source of uncertainty for polar regions as it can be minimised.

In accordance with the conclusions reached by Hawkins and Sutton, that recommend using model variety to recognize different sources of uncertainty, this dissertation will use a variety of models when forecasting future temperature change uncertainties for the globe and the Antarctic, keeping an appropriate sample size (Hawkins and Sutton, 2011).

CMIP5 Model Uncertainty

Mauritzen et al. (2017) add to Hawkins and Sutton (2009; 2011) by exploring uncertainty in CMIP5, concluding that model uncertainty within climate models is due to climate sensitivity, much like the conclusions of Hawkins and Sutton (2009).
Mauritzen et al. (2017) found that as time increases, so does the model uncertainty. By minimising model uncertainty, climate models can improve future scenarios' reliability, credibility, and legitimacy (Mauritzen et al., 2017).

Mauritzen et al., (2017) found that the only areas that maintained a high level of model uncertainty across all periods were the Arctic and the Southern Ocean regions; this would imply that when projecting future temperature uncertainties for CMIP6, the Antarctic will have a similarly higher model uncertainty. This is crucial information for policy makers, as it indicates a large range of future Antarctic surface air temperatures. This highlights low confidence in the modelling results, with model uncertainty needing to be acknowledged, so that the science is not questioned.

Social Uncertainty and Risk

Uncertainty can have different meanings depending on its context. Subsequently, there are multiple definitions of uncertainty. The following will explore the core definitions of uncertainty within social and environmental circles and how they relate and differ from definitions of risk.

Defining Risk and Uncertainty

There are many definitions of uncertainty within the sciences, social sciences, and political spheres (Shackley & Wynne., 1996). Sources of uncertainty can build upon one another, contributing to a higher sense of an individual's uncertainty regarding a situation (FeldmanHall & Shenhav, 2019).

Risk is when the outcomes are more or less known and anticipated by decision-makers or adaptational policymakers. However, when discussing *uncertainty*, the situation involves various parameters or outcomes that are unclear and unknown (Funtowicz & Ravetz., 1990; Wynne., 1992). Wynne (1992) elaborates that uncertainty is the unknowns associated with environmental risks due to 'lack of scientific knowledge' (Wynne, 1992, p.118). To elaborate further, FeldmanHall & Shenhav (2019) define uncertainty as the precision of a prediction based on previous information. How uncertain a situation or prediction is, depends on how many uncertainties are constrained within the situation or science. The uncertainty of Antarctic's future climate increases as the uncertainties in the modelling and socio-economic elements increase. If these uncertainties within the futures work are decreased, then the overall uncertainty in the Antarctic's future will decrease.

However, there will always be uncertainties involved within scientific experiments, modelling or testing (Funtowicz & Ravetz., 1990; Wynne., 1992). These uncertainties are similarly present in socio-economic elements, as there will always be aspects of the social world out of the control of researchers.

Epistemological uncertainty is where unknowns are within the bounds of knowledge (Derbyshire, 2020). *Ontological uncertainty* is the future unknowns that come as complete surprises (Derbyshire, 2020). Reducing model uncertainties will only reduce epistemological uncertainty; however, modelling does not help understand or predict ontological uncertainty (Derbyshire, 2020). For this reason, to reduce uncertainty within Antarctic futures, a cross-disciplinary approach must be made, where modelling is combined with socio-economic aspects.

An example of ontological uncertainty is the occurrence of COVID-19. Highlighted further in Chapter 3, coronavirus is predicted to affect the globe and the Antarctic significantly. COVID-19 was a surprise, a form of uncertainty unpredicted by futures makers. For this reason, this dissertation will not privilege model uncertainty but rather describe and evaluate uncertainties within both the modelling and socio-economic space for the Antarctic.

Policy and Communicating Uncertainties

Science can uncover knowledge that eliminates uncertainties; however, it can also mask other uncertainties (Wynne, 1992). Funtowicz & Ravetz (1990) argue that individuals who use quantitative data within the policy sphere will run into issues, with policymakers taking numbers or scientific advice for a fact, without context.

There are commonly little to no public policy outcomes for science-led projects and issues (Meah, 2019). It is not the specific uncertainties within science that discourage public policy decisions, as it is common for politics to contain uncertainties of their own. The difference in the science-policy interface is that scientists act as advisors to government officials on climate issues, often not placing the science in other contexts, such as the political viability of the advice; therefore, they end up acting as the boundary between public policy and science (Meah, 2019). Climate science must run parallel with public policy processes for science advice to work. Science and future projection work needs to acknowledge, understand and appropriately communicate uncertainties to policymakers. Policy advisors want a straightforward answer, even when the climate system is complex, with many uncertainties. It is incorrect to expect a singular number, or a temperature prediction, to be an exact representation of a future world.

As previously discussed, a risk society advances technologically, with previous risk assessment models becoming outdated with modernity. The side-effects of pollution grow to a level uncontrollable and challenging to manage and reduce. Chou (2018) believes that climate change is less an environmental problem than a political issue, where risk prevention and industrialisation policies are essential. The lines between politics and science are becoming blurred, with both spheres synonymous when regarding climate change.

Within a risk society, institutions are not always equipped to manage risks, resulting in political concerns associated with the distribution of ‘bads’ rather than ‘goods’ (Bulkeley, 2001). Institutions within a risk society begin to breakdown, as society starts to pin accountability to organisations due to lack of cohesiveness surrounding risk management discussions.

If climate change policies and actions are to be effective, action from all tiers of private and political institutions is crucial (Bulkeley, 2001). Furthermore, minimising uncertainties across all elements within a region is critical for effective climate change policies and adaptations (Wynne, 1992; Bulkeley, 2001). Improving model predictions is not good enough. This practice of refining climate science tools must combine with analysing ‘social commitments that build over the existing knowledge because it is here that ignorance and its corresponding risks are created’ (Wynne, 1992, p.115). Modelling and foresight work are two tools that help inform risk management teams and policy advisors. To ensure that Antarctic future scenario work is communicated effectively as informed policy advice, both the scientific and socio-economic uncertainties in the Antarctic must be identified and acknowledged.

1.3.3 DAPPs

Dynamic Adaptive Policy Pathways (DAPPs) is a policy and decision-making method within areas of significant uncertainties (Cradock-Henry et al., 2018; Haasnoot et al., 2013). The framework combines *Adaptive Policymaking* and *Adaption Pathways*. DAPPs involve steps, ensuring that uncertainties involved within policymaking are analysed and evaluated to ensure credible and relevant policy advice. The processes involved within the DAPP framework are copied from Derbyshire (2020) and are attached as Figure 6.

The DAPP system is a framework that minimises uncertainties within a policy environment. The DAPP process does not limit policy makers to choosing one future, rather, a range of potential options can be explored, allowing for more relevant adaptational policy making (Cradock-Henry et al., 2018). The work completed in this dissertation will serve as the early stages in the DAPP process (1 and 2 from Figure 6), so future work can be completed using the results, to inform polar policy advice.

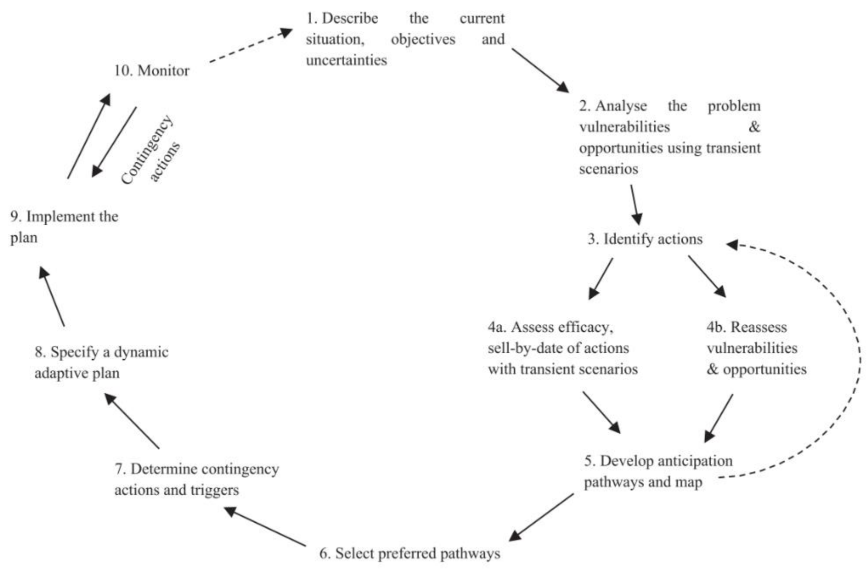

Figure 6 Processes Involved within DAPP, sourced from Derbyshire (2020)

Section 1.4 Research Aims

Polar models and futures studies are tools within the policy science interface, used for communication and political advice (Houghton et al., 1997).
Whilst Global uncertainties affect future scenarios, it is imperative that regional characteristics, including uncertainties, are analysed for credible, relevant and legitimate future scenarios that can aid in policy advice and development. In clearly analysing, quantifying and communicating uncertainties and risks within future scenarios, results will be more reliable and better understood.

With a focus on regional uncertainties applicable to the Antarctic, this dissertation aims to answer the following research question;

How do the physical uncertainties associated with Antarctic climate model projections and Antarctic socio-economic uncertainties combine to question the credibility, relevance, and legitimacy of Antarctic scenarios?

Understanding the model uncertainties helps quantify how reliable climate models are and how uncertainties manifest in future Antarctic temperature change predictions. Combining physical uncertainties with Antarctic socio-economic uncertainties results in a greater understanding of why future some Antarctic scenarios may not be credible, relevant, or legitimate.

As a conclusion of this dissertation, findings can be used for political advice, indicating ways to minimise uncertainties within the Antarctic modelling and socio-economic space.

For the aim of this dissertation to be met, three objectives will be completed.

1. To complete a sensitivity study, quantifying the sources of uncertainty associated with predictions for future global temperature, and future Antarctic temperature.

Hawkins and Sutton (2009; 2011) used the CMIP3 from AR4 to assess the limitations and unknowns within global and regional climate modelling. CMIP5 was released in 2014, with

CMIP6 due to be released in the AR6. The advancements made to these models can change the accuracy and minimise particular uncertainties within predictions.
The sensitivity study completed will use the models within CMIP6 to provide a more up-to-date analysis of global predictions. Furthermore, Antarctic temperature uncertainties will be projected for the first time. The modelling completed within this dissertation will be a new addition to work within the uncertainties in temperature predictions. The most crucial physical uncertainty for Antarctica, within temperature projections, will then be identified.

2. Uncertainties within Antarctic socio-economic elements will be determined and acknowledged. The largest source of uncertainty within the Antarctic socio-economic elements will then be identified.

The Antarctic socio-economic dashboard of elements proposed by Frame (2020a) will be used as the backbone for this research. A subset of Frame (2020a) elements will comprise a new dashboard, indicating the most important socio-economic elements to the Antarctic's future. Upon further research into these socio-economic elements, the associated uncertainties will additionally be included in the dashboard. By identifying what socio-economic element contains the most significant uncertainty, future scenario work can accommodate a range of possibilities, outlining how that element may change or develop with time. Subsequently, future scenarios would be more robust to the main uncertainties within Antarctic socio-economic elements.

3. The discussion of a risk society in relevance to Antarctic futures and climate change will place the findings of this dissertation in context.

Possible ways that a risk society and post-truth politics can magnify uncertainties within climate change will be discussed, and how this has relevance for Antarctic temperature modelling and future scenario making.

Hypothesis

Based on previous research (Hawkins and Sutton 2009; 2011), various hypotheses have been formulated on the modelling experiments completed within this dissertation.

When regarding the predictions for the uncertainties associated with future temperature projections, the hypothesis is that the results will show a significant difference between the three sources of uncertainty for the globe versus the values of the three sources of uncertainty for the Antarctic.

It is hypothesised that *internal variability* will be higher for the Antarctic than the globe and *scenario uncertainty* will be relatively similar for the globe and the Antarctic.
Finally, the *model uncertainty* for Antarctic future temperature projections, especially at larger time scales, will be far greater than the globe.

Chapter 2: Global and Antarctic Temperature Model Uncertainties

Section 2.1 Modelling Temperature Uncertainties

2.1.1 Global Temperature Model Uncertainties

The CMIP6 (Coupled Model Intercomparison Project 6) data uses 44 different climate models. Here, a subset of 19 models, have been used to project three different uncertainty sources and their amounts, for global, Antarctic and Arctic surface temperatures. Projections for the Arctic will act as a reference point for the Antarctic results. Table 4 in Appendix 1 lists the 19 models, and associated references, used in this work.

Hawkins and Sutton define the mathematics behind internal variability, model uncertainty and scenario uncertainty.

Internal variability is defined by:

$$V = \sum_{m} W_m \mathrm{var}_{s,t}\,(\varepsilon_{m,s,t})$$

'Where $\mathrm{var}_{s,t}$, denotes the variance across scenarios and time, and V is constant in time' (Hawkins and Sutton (2009), p.1103).

The equation below denotes model uncertainty as:

$$M(t) = \frac{1}{N_s}\sum_{s} \mathrm{var}_m^w\,(x_{m,s,t})$$

where var^w is the variance, weighted, on the different models and 'N_s is the number of scenarios' (Hawkins and Sutton (2009), p.1103).

Finally, the scenario uncertainty is described by:

$$S(t) = \mathrm{var}_s\left(\sum_m W_m\, x_{m,s,t}\right)$$

$S(t)$ is scenario uncertainty and changes with time.

The mathematics for internal variability, scenario uncertainty and model uncertainty described by Hawkins and Sutton (2009) was used as a starting point for the modelling completed in this dissertation. It should be noted that Hawkins and Sutton (2009) weighted CMIP3 models when determining the amounts and sources of uncertainty. This is where particular models, that are known to perform extremely well when representing certain processes, are given a larger weight over lesser performing models. This has been proven, in some cases, to decrease model uncertainty (Lorenz et al., 2018). However, for regions like Antarctica, where observational datasets are smaller, and there is greater internal variability, weighting particular models can create a greater uncertainty in the results (Weigel et al., 2010, p. 4175). There was no weighting of models in this dissertation, and thus the results represent a more simplified version of the modelling completed by Hawkins and Sutton (2009).

Only one time-series realisation from each of the models was used to determine the three sources of uncertainty for the 19 models in the dataset (Table 4). A polynomial fit was applied to each time series to 'provide the best approximation of the relationship between the dependent and independent variable' (Ayush, 2019). By using a polynomial fit, a wide range of patterns could be applied, which is required when determining the amounts and sources of uncertainty. Four RCP and SSP combinations were used in this dataset. Namely SSP126 (SSP1-RCP2.6), SSP245 (SSP2-RCP4.5), SSP370 (SSP3-RCP7.0) and SSP585 (SSP5-RCP8.5). This allowed for a range of outcomes to be assessed for their uncertainties, rather than calculating uncertainties for only one type of SSP or RCP.

The *natural variability* (internal variability) was derived by calculating the variance between the historical polynomial fit and the time series. This was further calculated for each of the RCP-SSP combinations.

The *model uncertainty* involved creating a two-dimensional array, with the polynomial fits of each model and model simulations as a function of time. Following this, variances of all polynomial fits and future scenarios were calculated, then averaged. The averages of all variances represented the model uncertainty, changing with time.

The *scenario uncertainty* follows a similar method to the model uncertainty. Both the polynomial fits of each model and model simulations as a function of time were input into a two-dimensional matrix. The mean was calculated for each future scenario, the variance on each average, corresponding with an associated time, resulted in the scenario uncertainty.

2.1.2 Antarctic Temperature Model Uncertainties

Derivation of the Antarctic Temperature Model Uncertainties utilised the same process used to simulate the Global Temperature Model uncertainties. However, to simulate the Antarctic projection, only regions poleward of 60° South were used in the analysis.

The model MCM-UC-1-0 did not contain data for South of 60°, resulting in its exclusion from the simulation. Subsequently, 19 CMIP6 models projected global uncertainties, and 18 CMIP6 models were used to simulate Antarctic uncertainties.
Arctic uncertainties were projected, following the same process as the Antarctic uncertainties; however, the region defined is situated over the North pole. The Arctic uncertainties were projected to act as a comparator for the Antarctic uncertainties.

Section 2.2 Temperature Uncertainty Projections

2.2.1 Temperature Model Uncertainties Results

Below are the projected model uncertainty results, internal variability, and scenario uncertainty for the globe, Arctic and Antarctic. The interpretation of these results can be found in the section *Temperature Model Uncertainties Discussion.*

Within simulations for the globe, displayed in Figure 7, *Natural Variability* is approximately 0.1°C^2. The *Scenario Uncertainty* for the globe displays an exponential pattern, with a maximum of 1.6°C^2 at 2100, intersecting with model uncertainty in 2070. *Model Uncertainty* for the globe exhibited a reasonably linear pattern, reaching 0.75°C^2 in 2100. Figure 8 displays the patterns for Arctic simulations. *Natural Variability* is approximately 0.25°C^2 and is more significant than that observed globally in Figure 7. *Scenario Uncertainty* for the Arctic again follows an exponential pattern with a maximum of 5.75°C^2 in 2100. In 2050, natural variability and scenario uncertainty intersect. Arctic model uncertainty begins at approximately 0.5, then follows a steep, relatively linear, incline reaching a maximum value of 7.6 in 2100. Interestingly the model uncertainty is considerably more significant than the scenario uncertainty in this region. Thus, improvements in climate model performance will likely significantly impact the reduction of uncertainties in this region.

Figure 9 shows the Antarctic temperature uncertainty projections. The Antarctic *Natural Variability* is 0.15°C^2 whilst the *Scenario Uncertainty* for the Antarctic is exponential, with a maximum of 1.6°C^2 in 2100. Antarctic *Model Uncertainty* begins at 0.15°C^2 and then follows a steep exponential incline, reaching a maximum of 2.1°C^2 in 2100.

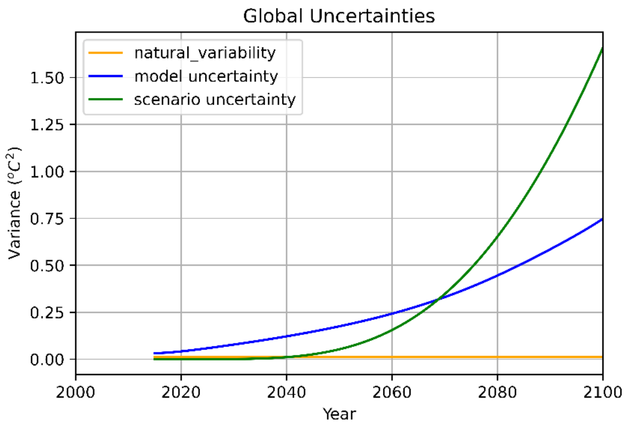

Figure 9 Global Uncertainty for Future Temperature Projections using CMIP6

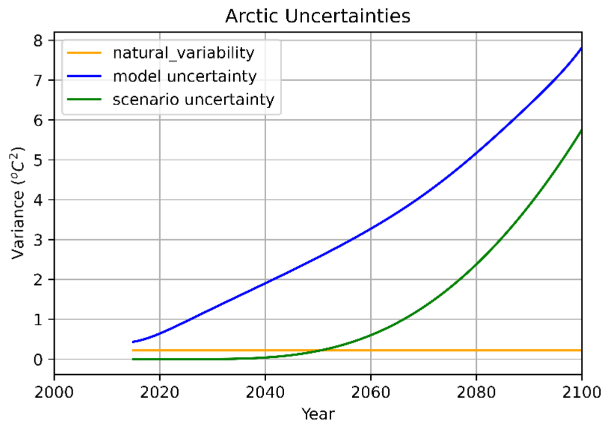

Figure 9 Arctic Uncertainty for Future Temperature Projections using CMIP6

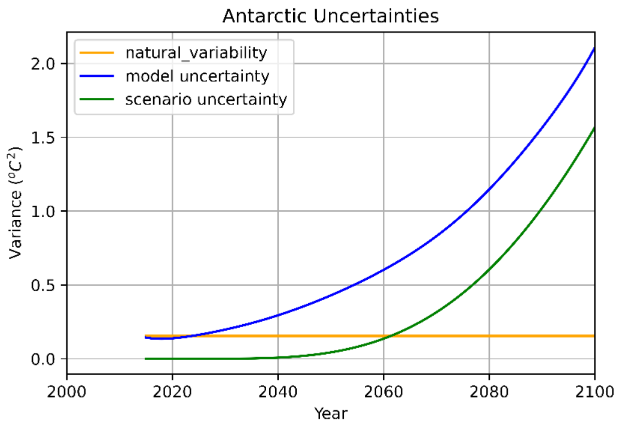

Figure 9 Antarctic Uncertainty for Future Temperature Projections using CMIP6

Both the Arctic and the Antarctic projections display more considerable model uncertainty than the globe. More significant model uncertainty over the poles is expected, as representations of climate interactions and processes over the polar regions can be poor in climate modelling. This will be discussed further in the next section; *2.2.2.* The Arctic model uncertainty is more significant than the Antarctic and the Global projections values of this uncertainty. Natural variability is similar in both the Arctic and the Antarctic but more considerable than in the globe projections. As will be discussed further in section *2.2.2*, natural variability is greater for polar regions due to polar amplification. Scenario uncertainty displays the same pattern across all three graphs, with the Antarctic and the Global projections maintaining similar levels, whilst the Arctic has higher levels of scenario uncertainty. The values for scenario uncertainty and model uncertainty are more significant for the Arctic than the Antarctic and the globe, with Arctic values of scenario uncertainty, natural variability, and model uncertainty being the greatest of all three simulations. As will be discussed in *2.2.2*, differences in uncertainty levels for the polar regions must be acknowledged, and communicated across the science-policy interface. For justified evidence-based policy decisions to be made, there must be an understanding of these uncertainties to ensure mitigation and adaptational changes are relevant to both the Arctic and the Antarctic specifically.

2.2.2 Temperature Model Uncertainties Discussion

<u>Scenario Uncertainty</u>

Model outputs rely heavily on their inputs. Depending on how these inputs change, the overall result will differ. Scenario uncertainty identifies the results of potential choices, with the scenario chosen to input into a climate model always having uncertainties associated with it (Hawkins & Sutton, 2009).

Scenario uncertainty, explained by Hawkins and Sutton (2009), is clearer over longer periods. (Hawkins & Sutton, 2009). CMIP6 modelling confirmed this, with scenario uncertainty presenting an exponential increase for the globe, the Antarctic and the Arctic.

<u>Minimising Scenario Uncertainty</u>

Minimising scenario uncertainty is difficult (Hawkins and Sutton, 2009), as there will always be uncertainties associated with choosing future conditions as inputs for climate models. This difficulty is presented in Figures 7, 8 and 9, where the scenario uncertainty increases with time. As previously explained in Chapter 1, socio-economic elements make up SSP narratives. SSP scenarios comprise the socio-political-economic portion of climate modelling, determining potential future climates. By evaluating socio-economic uncertainties, inputs into a climate model could be altered depending on what avenues of future societal change need to be explored. Based on their uncertainties, altering social inputs to a climate model could help to create more informed SSP decisions, therefore minimising scenario uncertainty. An example of this would be to create socio-economic inputs that explore the future of Antarctic governance and how different avenues of its future may affect other socio-economic elements, and how its different pathways may affect emission levels. This may decrease the amount of scenario uncertainty present in Antarctic climate models.

Model Uncertainty

Model Uncertainty cannot be derived from a single model, but the spread of model results for the same scenario after considering internal variability can be used to derive an estimate. Depending on the model's structure, a specific radiative forcing response will be different (Hawkins & Sutton, 2009).

Figures 7, 8 and 9 show that model uncertainty is present in projections for the globe, Antarctica and the Arctic. However, the model uncertainty is the most important source of uncertainty in the Arctic and Antarctica, with it displaying the highest levels of variance across all time scales. Higher model uncertainty in the Arctic is conclusive with the findings by Hawkins and Sutton (2009), where projections of uncertainty for Greenland had a lower S/N ratio than the rest of the globe. Greenland's low S/N was due to higher natural variability and model uncertainty over the poles due to poor representations of climate processes and unique climate feedback systems present over the Arctic region. Mauritzen et al. (2017) support this finding, with their results concluding that model uncertainty for CMIP5 models increased over time and was present in more significant amounts for regions situated over the Arctic and the Southern Ocean.

Minimising Model Uncertainty

Significant values in the model uncertainty for the poles are due to uncertainty in projecting the climate feedback loops within these regions (Hawkins and Sutton, 2009). Watson (2008) agrees that it is this presence of climate feedback loops that makes it more difficult for modellers to represent the climate system accurately. Observations over the next 30 years will decrease model uncertainties by supplying researchers with better understandings of how the climate responds to change (Watson, 2008).

Climate sensitivity is the climates' ability to react to change and 'measure how fast Earth responds to changes in atmospheric CO_2 concentration' (Mauritzen et al., 2017, p.1). This climate sensitivity can alter the model uncertainty at different latitudes.

Uncertainties surrounding how to accurately model solar variability, abrupt climate change, land use feedback, dust and biomass, and ozone changes contribute to a model's overall uncertainty within its structural components (National Research Council et al., 2005). Along with the previously mentioned interactions between different components of the Earth system, the poles include climate interactions not present anywhere else on the globe. The representation of clouds and sea ice largely dominate why model uncertainty is more prominent over the poles than the global average. Increased time and resources spent on model construction and observational datasets are required to decrease model uncertainty for the globe and polar regions. Subsequently, modellers can understand climate feedback loops through observations, altering models to reflect the appropriate changes, with projections that include the processes involved in climate feedback loops and enhanced future temperatures becoming more credible and robust. The decrease of model uncertainty is crucial for polar regions, as it is the dominating source of uncertainty.

Natural Variability

As previously discussed by Hawkins and Sutton (2009), *Natural Variability* occurs in response to an absence of radiative forcing at a given time. The internal climate variability within a model can disguise or intensify anthropogenic changes in the climate (Hawkins & Sutton, 2011).

Natural Variability plays the most critical role at shorter projection times and more minor spatial scales (Hawkins and Sutton 2009). This dissertation's projections support the importance of internal variability over smaller regions, with internal variability being more considerable for both the Antarctic and the Arctic than the globe.

Minimising Natural Variability

Natural variability is higher for regions situated over the poles. The phenomenon of polar regions expressing more considerable temperature changes due to perturbations is called polar amplification (Goosse et al., 2018). Goosse et al. (2018) explain that polar amplification equates to a more significant natural variability for the poles than the globe. However, Arctic polar amplification is greater than the Antarctic. Figure 8 and Figure 9 display the difference in natural variability between the Arctic and the Antarctic. Arctic polar amplification is due to:

(1) a relatively large and positive lapse rate feedback; (2) a relatively weak negative Planck response; and (3) a sizeable positive surface albedo feedback (Goosse et al., 2018, p. 7).

Antarctic polar amplification exists but is not as significant as in the Arctic due to a weak Planck response and a positive albedo feedback loop.
Natural variability is higher in regions over the poles, especially in the Arctic, due to internal variability associated with polar amplification, atmospheric circulation patterns (Deser et al., 2012), and sea ice loss (England et al., 2019).

Further evaluations are essential to understand the processes involved within a region's internal variability, both within projections and observations. There will always be natural variability within the climate system, however, it is the models ability to accurately represent this internal variability that must be advanced. A greater understanding of internal variability will decrease the uncertainty in temperature projections and aid with interpreting losses in sea ice (Neil C. Swart et al., 2015).

<u>Temperature Projection Uncertainties in the Antarctic</u>

Variance across all three sources of uncertainty was more significant for the regions situated over the poles than for the global average. However, the most crucial source of uncertainty impacting the poles is model uncertainty. Supported by previous literature (Hawkins & Sutton, 2009, 2011; Mauritzen et al., 2017), the poles incur more significant amounts of total uncertainty; however, this dissertation's crucial finding is that model uncertainty over the poles exceeds scenario uncertainty. This exhibits that the poles' environment is such that the level of uncertainty regarding physical changes is more significant than anywhere else on Earth.

Policy advisors working on mitigation and adaptational changes to help the climate must acknowledge the heightened uncertainty for polar regions. This acknowledgement is essential as the high levels of model uncertainty show that there is a wide range of possibilities of how polar regions may respond to global warming, and how much temperature rise may be imposed on the regions, depending on different SSP-RCP scenarios. The high model uncertainty for polar regions places a low amount of confidence in surface air temperature projections. Sources of uncertainty must be minimised for regions over the poles, so a greater understanding of how the Arctic and the Antarctic respond to change can be grasped; allowing for appropriate decisions to be made, protecting the vulnerable polar regions from degradation. Given that model uncertainty is the dominant source of uncertainty for the poles, it must be minimised if policymakers can be provided with accurate evidence and data to make adaptational decisions. Communication of these Antarctic temperature projection uncertainties between the science-policy interface is essential, to ensure policymakers do not question temperature projections as credible, relevant and legitimate, and are made aware of the need to develop more advanced climate models and comprehensive observational datasets for polar regions.

Chapter 3: Antarctic Socio-economic Uncertainties

Section 3.1 Antarctic Socio-economic Element Uncertainties

Uncertainties are not limited to the science and modelling space of futures studies. The socio-economic impact that humans have on the Antarctic by visiting the continent and utilising its resources also creates various uncertainties.

The following section reviews the uncertainties within Antarctic socio-economic sector, using the dashboard of Antarctic socio-economic elements and their associated uncertainties (Table 5).
A definition of each socio-economic element from Table 5 will also be included.

This dashboard is based on the elements proposed by Frame (2020a); however, they have been assessed to identify the elements most crucial to the Antarctic's future. Not all elements have associated indicators; however, certain elements have been considered complex enough to require sets of indicators.

For ease of reading, the socio-economic elements impacting future Antarctic scenarios (from the dashboard Table 5) have been split into seven categories and are listed as follows:

1. Institutions and Governance
2. Economic Impact
3. Direct human Impact
4. Ecological and Environmental Processes
5. Resource Exploitation
6. Technological Development
7. Broader Societal Factors

Chapter 4 will highlight the uncertainties across Antarctic socio-economic elements deemed to have the most impact.

As previously discussed, O'Neill et al. (2017) proposed a set of 24 socio-economic elements, providing an overview of global challenges to inform adaptation and mitigation strategies in efforts to reduce global emission levels and temperature rise. The global elements proposed by O'Neill et al. (2017) are helpful, as they allow study into how each socio-economic element can shape future global change. These elements are attached in Table 2.

Building on O'Neill et al. (2017), Frame (2020a) evaluated the 24 global elements and reduced them to 17 socio-economic elements that would specifically impact Antarctica's future. The entire dashboard of Antarctic specific elements proposed by Frame (2020a) is attached as Table 3. As previously discussed, Frames elements focus on the *regional* rather than *global* to provide researchers with a more accurate picture of socio-economic and political elements pertinent to the Antarctic's future.

1. Institutions and Governance

1.1 Antarctic Governance

The Antarctic Treaty System (ATS) is the governing mechanism of Antarctica, and the Antarctic Treaty is the most fundamental piece of legislation within that system. The Antarctic Treaty was drafted in December 1959 due to international pressures caused by territorial claims on the Antarctic following the Cold War (Rothwell & Hemmings, 2018). The Treaty was signed to revoke territorial claims and maintain Antarctica as a continent preserved for peace and science. With only 14 annexes included within the legislation, the Antarctic Treaty reflects Antarctica's core issues at the time (Rothwell & Hemmings, 2018). Interested parties have grown, and additional groups have since been established to advance discussions around concerns that have emerged since 1959. These groups, as well as the Treaty itself, form the Antarctic Treaty System.

The Treaty itself holds little regulative enforcement agency. Instead, disputes or altercations are solved through international meetings and discussions (Bunikowski & Hemmings, 2021). Originally 12 states signed the Antarctic Treaty, all who now hold *consultative* party status. This number has since grown to 29. Consultative parties have the right to vote and raise a voice at the biannual Antarctic Treaty Consultative Meetings (ATCM). Unlike consultative parties, *non-consultative* states (*Observer* parties) to the ATS, currently 24, cannot raise concerns or voice opinions on Antarctic matters; however, they can still attend ATCMs (Rothwell & Hemmings, 2018). The Antarctic Treaty also allows any United Nation (UN) member to sign the legislation ("The Antarctic Treaty Explained - British Antarctic Survey," n.d.). Although numbers of states signed to the Antarctic Treaty have risen since 1959, it is increasingly difficult for countries to join as consultative parties raising concerns regarding the ATS' exclusivity (Rothwell & Hemmings, 2018).

1.1a CCAMLR

In 1980, the ATS established the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR) to advance further the discussions on Antarctic marine life and resources issues [2]. Previous to CCAMLR, the Antarctic Treaty did not include any provisions specific to the Antarctic marine environment. Members of CCAMLR are not necessarily signatories of the Antarctic Treaty, and although CCAMLR is included within the ATS, it is recognised as a separate organisation, as it includes the participation of governments that have interests in the Southern Ocean, but not the Antarctic continent (Bunikowski & Hemmings, 2021). Each year, CCAMLR meets in Hobart to discuss any jurisdictional issues (Hemmings, 2020).

1.1b Madrid Protocol

The Madrid (Environmental) Protocol was negotiated at the 11th ATCM and signed in 1991 (Secretariat of the Antarctic Treaty, n.d.). The Madrid Protocol focuses on implementing environmentally responsible practices and designates Antarctica as a 'natural reserve.' The Committee for Environmental Protection was developed, with the group providing advice to states on how to best conduct themselves whilst on the Continent. Within the legislation, ANNEX V was ratified in 2002, designating specific sites or areas to be preserved and protected[3] (Australian Antarctic Program, 2019).

As will be expanded upon in Chapter 4, Antarctic governance pervades all Antarctic socio-economic elements. This places great importance on its resilience, relevance and effectiveness. As politics evolve and priorities of power or wealth increase, the Antarctic could be exploited. There is significant uncertainty with how the ATS will respond to global conflict and whether its framework is resilient enough to handle too much global change or political pressure (Walt, 2017).

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[2] Currently, CCAMLR designates the 'Antarctic' ocean boundaries; as anything further south than 60° South (Bunikowski & Hemmings, 2021).

[3] More information on Antarctic protected areas are included in Appendix 2.

2. Economic Impact

Antarctica is a continent filled with valuable resources and flora and fauna. The ATS contains provisions that outline the desire for the Antarctic continent to be reserved for peace and science. Nevertheless, there are increasing pressures to advance economic development in the region at the potential expense of the environment. The uncertainties within the space constrain the ability for Antarctica to remain environmentally protected from potential economic elements such as bioprospecting, fisheries and tourism.

2.1 Bioprospecting

Biological prospecting (commonly bioprospecting) is the investigation of flora and fauna for commercial and medicinal purposes. It involves multiple steps, from 'discovery and sampling to subsequent research and development, manufacturing and marketing' (Herber, 2006, p. 139).

Therefore, bioprospecting has benefits for both scientific and academic research purposes, and industry-specific priorities, with 'the interface between the two often obscure' (Herber, 2006, p. 139). Practised globally, bioprospecting in Antarctica is gaining an increasing amount of interest (Senior, 2004).

To ensure the activity of bioprospecting upholds the aims of the ATS, it needs to be sufficiently regulated. There is a need for a policy specifically on the regulation and management of bioprospecting in Antarctica. This policy must work with current international laws and the ATS (Herber, 2006; Senior, 2004). The ATS currently does not explicitly state any rules specific to bioprospecting; however, the Madrid Protocol broadly aims to limit any environmental degradation resulting from Antarctic activities, including adverse effects on flora and fauna (Senior, 2004). The Madrid Protocol facilitates cooperation between signatory treaty parties to plan and implement any activities or scientific endeavours. The inclusion of Environmental Impact Assessments before any scientific activity ensures that any Antarctic bioprospecting is analysed to assess any impact on organisms or their surrounding environment.

The Convention on Biological Diversity (CBD) and the United Nations Convention on the Law of the Sea (UNCLOS) provide frameworks and regulations for biological activities, including bioprospecting. However, the CBD and UNCLOS have limitations in managing bioprospecting explicitly in Antarctica (Herber, 2006). The CBD has jurisdiction over state territories, and the UNCLOS has jurisdiction over international waters, but neither directly refer to bioprospecting in Antarctica. The Biodiversity Beyond National Jurisdiction (BBNJ) could be adapted to include Antarctica within its structure, but this would create issues regarding how the ATS and the BBNJ may compete for jurisdictional rights (Nickels, 2020).

It appears that current provisions within the Antarctic Treaty and the Madrid Protocol only discuss bioprospecting as a scientific-based activity. Nevertheless, with increasing technology and a heightened interest in Antarctica's role within the medicinal and commercial sphere, Antarctic bioprospecting will likely increase in the future in ways other than scientific research. (Senior, 2004)

The lack of Antarctic bioprospecting regulation is of grave concern and creates considerable uncertainty. Currently, control over bioprospecting depends on the cooperation of states within the boundaries of vague rules. The uncertain future of Antarctic governance controls the future of bioprospecting and its subsequent impact on the Antarctic environment and ecosystem.

2.2 Fisheries

The most up to date information and statistics on Antarctic fisheries are from the CCAMLR website (CCAMLR, 2019). All fishing vessels operating in the Southern Ocean must report catch data to CCAMLR on a daily basis to continue to fish in the region. Krill, Toothfish and Icefish are the three most common types of catch in the Southern Ocean. CCAMLR provides an open-access statistical database on the catch history for all three and overviews based on country (CCAMLR, 2019).

Currently, CCAMLR manages how many of each species of fish can be caught by fisheries[4]. With CCAMLR being a subsidiary of the ATS, the Antarctic Treaty must be upheld so CCAMLR can continue to protect and monitor these waters. However, the uncertainty lies with the strength of the ATS. Governments that currently govern the fishing in the Southern ocean can face domestic political or fiscal pressures that could impact their contribution in

[4] Specific catch numbers on toothfish, icefish and krill are attached in Appendix 2.

the area. Likewise, the international rules-based order has little influence over powerful nations that exploit existing agreements.

Furthermore, Antarctic marine ecosystems within the Antarctic can be impacted by environmental change. Ecosystem, environment, and predator change are all examples of changes that may alter how a fish species inhabits its environment (Antarctic and Southern Ocean Coalition, 2020). How krill will react to environmental factors is important as catch numbers are so significant[5]. The specific uncertainties regarding krill are associated with inaccurate estimations of population size and how they will respond to ocean warming (Bender, 2006; Meyer et al., 2020).

Limited knowledge of individual species life cycle leads to further uncertainties within the Antarctic fishing industry. For example, toothfish are incredibly long-living species, in which there are uncertainties associated with how they may respond or recover from overfishing (Antarctic and Southern Ocean Coalition, 2020). Although CCAMLR may set yearly catch limits on toothfish, it is unknown if this regulation assures sustainable fishing (Antarctic and Southern Ocean Coalition, 2020).

2.3 Tourism

The International Association of Antarctica Tour Operators (IAATO) is a non-profit industry alliance formed in 1991, regulating the exposure of tourism in Antarctica ("IAATO & The Antarctic Treaty - IAATO," n.d.). In 2011, it was decided at the Antarctic Treaty Consultative Meetings (ATCM) to adopt the General Guidelines for Visitors to the Antarctic under resolution 3. This provided tourism companies and organisations with a set of regulations and guidelines before allowing tourists to visit the continent. All visitors are required to adhere to the Antarctic Treaty rules, which include completing appropriate permits before visiting specific regions ("IAATO & The Antarctic Treaty - IAATO," n.d.).

Since 1991 IAATO has been collecting annual tourist data. Information is gathered on nationality and whether tourists visiting on vessels are landed. (IAATO, 2020a). Tourist numbers increased by 600% from 1991 to 2013. Below is a summary of data from the latest years (2018-2019).

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[5] See Appendix 2.

2018-2019

Total tourists (Landed and Cruise Based) : 55,489

Landing Tourists: 44,600

Cruise only: 10,889

The majority (32%) of these (total) tourists were from the USA, with 15% of tourists from China and 12% from Australia.

IAATO provides fact sheets for public use, along with statistics, describing past trends in tourism numbers.

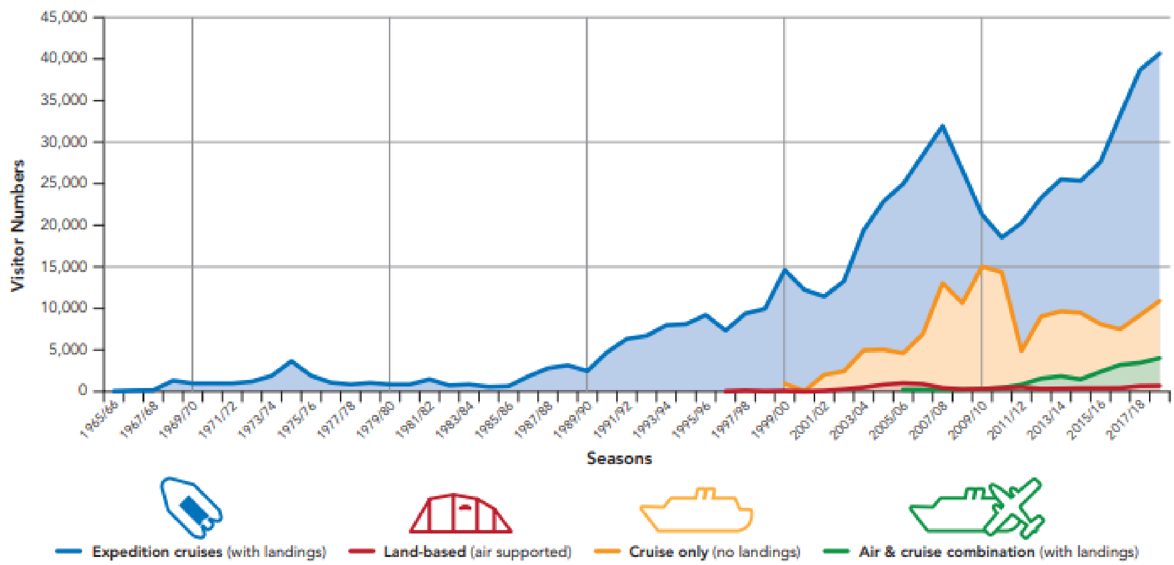

Figure 10 Total Antarctic visitor numbers from 1965-2018 (IAATO, 2019)

As shown in Figure 10, there has been an increase in tourism to Antarctica since 1965. There was a sharp decline in numbers following 2009, to which IAATO attributes this to the financial crisis. A similar trend is expected following the impact of COVID-19, which has seen a sharp decline in cruise tourism globally and in Antarctica. It is theorized by Frame and Hemmings (2020) that due to many cruise companies shutting down, it will be challenging for the Antarctic cruise industry to recover from COVID-19 (Frame & Hemmings, 2020).

In October 2020, IAATO released a statement that COVID-19 may not impact Antarctic tourism to the extent it was affected by the 2009 financial crisis, as vaccinations could play a role. However, vaccinations are still a future thought, with tourism to the Antarctic having to undergo an extensive recovery period (IAATO, 2020c). Furthermore, as international travel recommences, the challenges posed to Antarctic tourism will be prominent, with quarantines and regulations likely to be imposed (Frame & Hemmings, 2020). It is also possible that due to changing technologies and a changing world, the future of Antarctic tourism may take an entirely new format (Frame & Hemmings, 2020).

Not only are the numbers of tourists difficult to predict, the future of Antarctic tourism and its indirect effects on the environment will be heavily impacted by the modes of transportation used. A tourist on a cruise ship uses more energy than an individual travelling by plane (Walnum, 2011). Holland & Holland (2012) state that ‘a cruise liner such as Queen Mary 2 emits 0.43kg of CO^2 per passenger mile, compared with 0.257kg for a long-haul flight’ (Holland & Holland, 2012 p. 64).

The uncertainty regarding the future mode of travel will impact the climate adding to the emergency. Figure 10 depicts cruise ship tourism to the Antarctic, increasing more than air travel over the past 50 years. Depending on the preferential mode of tourism in Antarctica, the amount of GHG emissions released in the Antarctic atmosphere could increase or decrease.

Other uncertainties regarding tourism include the impact on the natural environment, influenced by regulations and tourist numbers.
Given the isolation and difficult weather conditions that the continent has, any tourism ventures come with a level of risk and uncertainty (Amelung & Lamers, 2005). This can be seen in the Erebus disaster case, when a passenger plane crashed into Erebus mountain, killing 257 people. The Erebus crash not only was a disaster that cost multiple human lives but also prompted an expensive and challenging search and rescue effort, along with impacting the surrounding environment (Amelung & Lamers, 2005).

3. Direct Human Impact

3.1 Research Community and Support

Further are the uncertainties regarding science and the upkeeping of research stations. The Antarctic Treaty Consultative Parties (ATCP) have not directly responded to these challenges (Rothwell & Hemmings, 2018).

There are 112 research facilities located in Antarctica. These comprise 84 stations, 11 camps, six refuges, six airfield camps, two laboratories and three depots. Forty-one of these total stations are open year-round, whilst the remaining 71 are seasonal stations.

Uncertainties within the Antarctic research community range from environmental impacts of stations and transport, to individual mishaps when working in the Antarctic environment. Although treaties such as the Madrid Protocol are in place to prevent any adverse environmental impacts due to research on the ice, mistakes resulting from human error, or unknowns, can still occur.

In 2018 the Council of Managers of National Antarctic Programs (COMNAP) developed a database to store information regarding the direct impact humans have on the Antarctic environment (COMNAP, 2018). The database currently includes fourteen sets of elements, all providing data on specific variables that National Antarctic Programmes (NAPs) or organisations within the Antarctic Treaty System can use and analyse[6].

3.2 Physical Impact

3.2a Search and Rescue

In 2019, COMNAP produced a report suggesting how to improve search and rescue coordination across parties (COMNAP, 2019). Critically, it was noted that search and rescue efforts increased with increased 'science, tourism, fisheries and commercial aviation with routing that crosses below 60° South' (COMNAP, 2019, pg. 4).

Economically, search and rescue to a remote region such as Antarctica can be costly due to temperature extremes, reduced daylight hours, and storms that make search and rescue efforts difficult (N. Mills & H. Mills, 2011). Any search and rescue operations in Antarctica depend on the specific situation and involve many uncertainties. Successful search and rescue efforts are dependent on operational planning and coordinated efforts between NAPs (N. Mills and H. Mills, 2011, p.41).

[6] The COMNAP database is not freely accessible to the public; however, the COMNAP website does include a comprehensive set of data on Antarctic field stations and any vessels employed by NAPs.

Unsuccessful search and rescue efforts can result in further accidents that can negatively affect the surrounding Antarctic environment and ecosystems.

Communication between Rescue Coordination Centres (RCC's) and NAPs is crucial to the success of a search and rescue effort (N. Mills and H. Mills, 2011). All countries with RCC jurisdiction must work cohesively and align priorities of sharing and distributing resources to the Antarctic. The five countries with RCC jurisdiction are the five gateway cities to Antarctica and all are original signatories of the ATS. The ATS's success is crucial in maintaining Antarctic search and rescue priorities and facilitating effective communication between the five RCC's and NAPs.

3.2b Microplastics/Carbon Footprint

The presence of microplastics in Antarctica is a recent and emerging area of research. The majority of current studies focus on the presence of microplastics in the Antarctic marine environment (Waller et al., 2017; Evangeliou et al., 2020).
However, in recent years, studies are starting to emerge that have found microplastics within Antarctic ice cores and land (ice) based microplastics. The distribution of terrestrial-based microplastics is most likely due to atmospheric transport (Kelly et al., 2020; Zhang et al., 2020).Studies have suggested that microplastics may have been distributed from local sources, such as national Antarctic stations.

A research station's carbon footprint is challenging to assess, as it involves the estimation of the amount of fuel used by individual stations, traverse trips, transportation, and research field trips; however it has been stated that there is a large carbon footprint present within the human Antarctic scientific research community (Winter, 2019). Along with the carbon footprint produced by transportation and the upkeeping of stations, oil spills and accidental pollution can occasionally occur. This has a detrimental impact on the surrounding ecosystem and environment (Bargagli, 2008). Therefore, it is a priority for NAPs to issue statements and plans that help to prevent these accidents and minimize the carbon footprint of researchers and stations (British Antarctic Survey, 2015; Antarctica New Zealand, 2020).

Accidental contamination can result from human error or abnormal weather conditions or events. It is difficult to prevent these issues from occurring. However, the presence of environmental impact statements (Antarctica New Zealand, 2020) and other methods that

NAPs employ to report incidents, allow trends to be examined, potentially decreasing accidental spills from occurring in the future. New emerging technologies may make pollution easier to manage, with zero-emission stations being a possibility in the future (Winter, 2019). However, this is still an uncertainty, as technologies that do not exist yet pose questions regarding their side effects, ability to work, and development timeframe.

Underlying all these uncertainties is the continuing ability of the ATS to uphold measures to maintain the protection of the environment. Whilst NAP's commit to uphold environmental protection in the region, if signatory nations' priorities change, there will be increased pressure on the ATS, possibly at the expense of the Antarctic continent's environmental protection.

3.2c Wildlife

Outlined by Woehler et al. (2014), the presence of humans on the Antarctic continent can be split into four categories;

1. *tourism and non-governmental activities,*
2. *scientific research,*
3. *commercial fisheries and;*
4. *whaling*[7]

Effects of these four categories can all have direct negative impacts on wildlife. The introduction of disease and or non-native species are additional threats to Antarctic wildlife, not classified as 'direct' human interactions.

<u>Tourism</u>

With increased Antarctic tourism comes increased direct human engagement. Cruise ships deliver people to shore, where humans interact with the environment. As explained previously, although IAATO monitors and provides regulations for tourism companies to follow, there is no monitoring of the impact humans have on population dynamics and disturbances (Woehler et al., 2014).

[7] Information on Antarctic Whaling can be found in Appendix 2.

Scientific Research

Antarctic stations are often on ice-free areas, therefore taking up space where wildlife would originally nest and raise their young (Woehler et al., 2014). Woehler (2014) explains that any research stations built after the signing of the Madrid Protocol would have been subject to an Environmental Impact Assessment. Any impacts that the building process may have had on the continent would have been evaluated and minimised if possible. The largest contamination source from research is oil and fuel spills and sewage runoff, which usually is only minimally treated (Woehler et al., 2014).

Commercial Fisheries

Whilst the role of CCAMLR is to regulate Antarctic fishing, unregulated, illegal fishing continues (Woehler, 2014). Woehler (2014) further states that illegal fishing continues to create an environment highly unsustainable to a range of Antarctic fish species. As technology advances, fishing of krill will also likely increase, which will affect the overall krill population, impacting the surrounding ecosystem. (Woehler et al., 2014).

4. Ecological and Environmental Processes

4.1 Physical environment

4.1a Temperature

Global Temperature Observations

The IPCC states that the climate system has been warming and accumulating heat since 1998 (IPCC, 2014). Human-induced greenhouse gases and natural variability contribute to the rise in CO_2 concentrations, which affect the radiative forcing and subsequent temperature present within the climate system (IPCC, 2014, p.43). Although the climate system has warmed over the past decade, there are fluctuations in this increased rate due to changes in natural variability, with volcanic and solar cycle cooling. Despite this, the climate system has increased in heat uptake more significantly than the previous average, primarily due to the oceans' ability to absorb heat (IPCC, 2014, p.43).

Antarctic Temperature

The IPCC summarises past trends of air surface temperature within the Antarctic continent in their report on Polar Regions (IPCC, 2019). Figure 11 shows how these RCP scenarios may affect the Antarctic (SCAR, 2017). Over the past 30-50 years, there were non-consistent

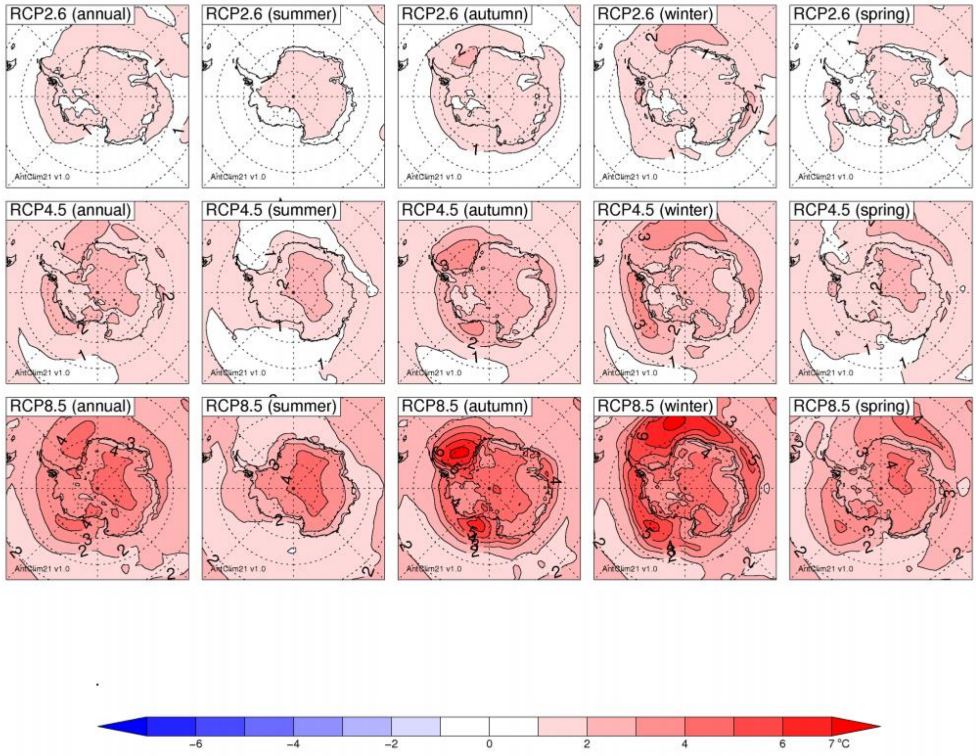

Figure 11 Projected Antarctic Temperatures for 2100. Forecast by AntarcticClimate21 (SCAR, 2017)

Antarctic surface air temperatures, with warming observed over the West Antarctic ice sheet but no rise over the East Antarctic ice sheet. The explanation for this is the variability within the oceans' ability to uptake heat and variable atmospheric circulation patterns (IPCC, 2019). Furthermore, the report discusses the interaction between air surface temperatures and the Antarctic ozone hole. The report states that 'ozone depletion has been the dominant driver of the positive trend in the Southern Annular Mode (SAM) during austral summer from the late 1970s to the late 1990s' (IPCC, 2019, p. 212).

4.1b Oceanographic

<u>Observed Changes in Ocean</u>

The ocean has incurred the most dramatic warming out of the entire climate system absorbing the majority of energy 'with only about 1% stored in the atmosphere' (IPCC, 2014, p.40). The warming is most significant near the surface, warming approximately 0.11°C per decade over 1971-2010. In terms of ocean makeup, the IPCC states that 'it is very likely that regions of high surface salinity, where evaporation dominates, have become more saline, while regions of low salinity, where precipitation dominates, have become fresher since the 1950s' (IPCC, 2014, p.40). This means that fish species will have to adapt to warmer temperatures and increased salinity levels raising further uncertainties.

Predicted Changes in Ocean

As observed, the ocean will continue to warm throughout the 21st century, with the most dramatic warming occurring in the upper ocean, in tropical and northern regions (IPCC, 2014). The Southern Ocean will incur the most significant deep ocean warming (IPCC, 2014).

Observed Changes in Sea Level

The IPCC explains the recent sea-level trends, with an average rise of 0.19m from 1901-2010, with the rate of increase higher than the previous two millennia (IPCC, 2014). This increase is due to the combination of thermal expansion and glacier melt (IPCC, 2014). Ocean circulation dominates the observed average sea level in any given region. The average for any broad area can be several times larger or smaller than the global mean.

Predicted Changes in Sea Level

With warming oceans and air temperature, sea level will continue to rise throughout the 21st century (IPCC, 2014). The IPCC projects that global sea level will rise under all RCP scenarios, with the rate of increase being more extensive than the observed 2mm/yr rate (IPCC, 2014). This sea level, however, as observed, will not increase at the same rate across different regions, with approximately 70% of global coastlines experiencing a rise in sea level of more or less than 20% of the global mean (IPCC, 2014).

4.1c Cryosphere

Observed Changes in Cryosphere

Ice sheets from both Greenland and Antarctica have been melting and contributing to sea-level rise over the past two decades (IPCC, 2014). The trend in the loss of sea ice in the Arctic is apparent, with sea ice decreasing in the region every decade since 1979. This trend is observed differently in the Antarctic, where the loss of sea ice is due to regional variability (IPCC, 2014).

Predicted Changes in Cryosphere

There are projections for significant reductions in Arctic sea ice, with an RCP8.5 scenario resulting in medium confidence that the Arctic Ocean will eventually be virtually ice-free in the summer months (IPCC, 2014). The predictions for sea ice changes are similar in the Antarctic; there will be a reduction in sea ice, but predicted with low confidence.

All glaciers (excluding Antarctic and Greenland ice sheets) are projected to decrease in volume. RCP2.6 projections decrease glacier volume from 15-55%, whilst RCP8.5 decrease glacier volume from 35-85%, predicted with medium confidence (IPCC, 2014).

With increasing climate troubles, the impact of global warming on the Antarctic is a subject of increasing relevance. Hughes (2018) states that the IPCC interacts with the ATS through communication with the ATCM and the Scientific Committee for Antarctic Research (SCAR). The IPCC aims to provide information regarding climate change, and by working with SCAR, it can communicate important information to ATCP.

Uncertainties in predicting and measuring the Antarctic physical environment result from unknowns and uncertainties within modelling. These, as previously described in this dissertation, are modelling uncertainty, natural variability and scenario uncertainty (Hawkins & Sutton, 2009).

However, uncertainties involving the future of the Antarctic environment are also associated with individual countries' response to climate change and global efforts. Increased communication between the IPCC and the ATS members allows a more cohesive response to climate change, as the adverse effects of global warming threaten to impact the Antarctic continent in a way that disrupts the preservation of the Antarctic as a region for peace and science. Any disruption to the successful operation of the ATS would decrease the benefits of cohesiveness and collective response.

4.2 Ecological processes

The CCAMLR Ecosystem Monitoring Program (CEMP) was established in 1989 as a long term programme monitoring the population of keystone species (Agnew, 1997). A change in populations of keystone species will reflect a change in the overall ecosystem's health or prosperity. The CEMP works to

1. recognise any changes in species size or critical parts of the ecosystem.
2. determine whether changes are results of environmental change or mainly due to human commercial harvesting.

CEMP was set up to determine how ecological processes are changing due to global warming and increased human activity with the environment. The uncertainties surrounding ecological processes are very much dependent on future change and how Antarctic ecosystems will respond to that change.
Similar to previously discussed socio-economic elements, the monitoring and subsequent knowledge of how ecological processes will change in the Antarctic is also dependent on the ATS's success. There is a possibility that long term monitoring programmes like CEMP would be discontinued if the ATS was not functioning as it should.

4.3. Biological Invasions of Non-Native Species

The increasing presence of humans in the Antarctic increases the risk of bringing Non-Native species to the continent accidentally. These species can be of high risk to Antarctic native species as they can bring disease or damage the ecosystems by disruption. Literature suggests that the highest risk of biological invasions of non-native species to the Antarctic is in the Southern Islands and close to the Antarctic peninsula (Hughes et al., 2015, 2020; McGeoch et al., 2015). These northern areas of the continent are ones frequently visited by tourists, with large numbers of people being shipped or flown in at any given time.

The uncertainties with a biological invasion of non-native species increase as tourism increases. Uncertainties arise with the compliance of tourism companies and individuals with IAATO rules, the ability of the Antarctic Treaty System to enforce the regulations, and the continuation of the IAATO if the ATS is dysfunctional.

5. Resource Exploitation

5.1 Minerals extraction

Coal and iron ore are present beneath the Antarctic ice sheets; however, mining to obtain these minerals is challenging and expensive (Australian Antarctic Program, 2020; Coburn, 2018). Due to the challenges posed by the climate and conditions, the prospect of mining in Antarctica is currently unprofitable (Cullen, 1994).

The Madrid Protocol bans all mining in Antarctica due to the negative environmental impacts. However, the protocol only enforces the ban on mining until 2048, when it will be reviewed. There is uncertainty surrounding the 'warming climate and advent of new technologies' (Coburn, 2018, p.1), affecting how safe, profitable, and environmentally friendly mining could be in the Antarctic. Therefore, these uncertainties will direct the future of Antarctic mining, potentially making extraction a realistic venture in the future.

6. Technological Development

6.1 Research priorities

In 2014, the Scientific Committee on Antarctic Research (SCAR) published a horizon scan for future Antarctic research priorities (SCAR, 2014). Future priorities were decided by 75 scientists and policy experts, combining various topics and subject matters. The six broad research categories were to:

1. *'define the global reach of the Antarctic atmosphere and the Southern Ocean;*
2. *understand how, where and why ice sheets lose mass;*
3. *reveal Antarctica's history;*
4. *learn how Antarctic life evolved and survived;*
5. *observe space and the Universe; and*
6. *recognise and mitigate human influences' (SCAR, 2014).*

The six categories of research priorities define where current and future funding and resources will be allocated, including technology development. However, as O'Reilly (2018) pointed out, research must be directed towards, or applicable for, policy-makers, with science not always being automatically accepted. Research must be conducted that is geared towards fitting into the complex workings of a policy world rather than focusing on the science alone (O'Reilly, 2018). The climate emergency demands immediate action. Unless climate research conducted in the Antarctic is built to run alongside policy, positive changes to the environment will not occur as quickly as desired.

Uncertainties within future research priorities for the Antarctic are minimised by the SCAR horizon scan, as research is given importance. However, research focuses change as priorities or funding allocation changes. There is uncertainty surrounding the specific directions that NAPs may want to direct their research.

6.2 Geoengineering

A developing technology within the Antarctic is the concept of geoengineering glaciers. This giant engineering project would physically intervene with glacial melt to slow sea-level rise. Scientists proposing the concept believe it is essential to take a next-level approach to pre-emptively stop sea-level rise (Moore et al., 2018).Furthermore, global engineering efforts, particularly the ability to remove CO^2 directly from the atmosphere, could help to tackle the climate emergency (Shepherd, 2012).

The concept of geoengineering in the Antarctic has been criticised though, with its potential impact on the environment being questioned (Moore et al., 2018). When viewed within the context of a risk society, geoengineering would further use developments in science and technology to help solve the unintended consequences of industrialisation; nevertheless, this in itself could incur more unintended 'bads'. Geoengineering in the Antarctic is still a concept yet to be used within the continent and it's future depends on the future priorities of governments and NAPs.

7. Broader Societal Factors

7.1 Dominant global attitudes to the environment

Global attitudes to the environment will influence how the Antarctic's future is managed. For the ATS to maintain power and legislative control, signature states must continue to prioritise the importance of the environment.

A 2018 study conducted by the Pew Research Centre found that most countries surveyed viewed climate change as a significant threat (Fagan & Huang, 2019). However, this was not the case in all countries, with 20% of countries viewing climate change as a minor threat and 9% believing it is not a threat. It was found that countries with a higher level of education had increased amounts of people believing that climate change was a significant threat (Fagan & Huang, 2019).

The dominating view towards climate change and the environment will dictate the future of the Antarctic continent. If enough states believe that mitigating climate change is a top priority, then research directions and governing bodies will reflect this view.. The Pew study found that the number of countries that viewed climate change as a significant threat had increased since 2013 (Fagan & Huang, 2019).

7.2 Ontological Uncertainty: COVID-19

COVID -19 is an example of ontological uncertainty. With no warning, COVID-19 has impacted the globe and the Antarctic on an unprecedented scale. COVID-19 has provided many uncertainties within the Antarctic socio-economic space. It is unknown how tourism will respond to the pandemic, with current tourism to the Antarctic suspended (Frame & Hemmings, 2020). Using the global financial crisis as an example, it could be possible that tourism does not return to previous levels for ten years. When tourism does increase to levels similar to pre-COVID-19, there is uncertainty surrounding what form Antarctic tourism will take.

Similarly, Antarctic research has decreased due to COVID-19 (Frame & Hemmings, 2020). This raises questions regarding the future of Antarctic research and what effects it will have if it continues to decline.

As previously outlined, Antarctic Governance and decision making via the ATS occurs at the annual ATCMs, and the yearly CCAMLR meetings in Hobart (Hemmings, 2020).

The 2020 ATCM meeting was cancelled due to the coronavirus pandemic. The next scheduled ATCM meeting is due to be held in Paris, France, from the 14th-24th of June 2021 (Secretariat of the Antarctic Treaty, 2020).

IAATO held a meeting on July 3rd 2020, to discuss the industry response to COVID-19. The meeting was held virtually; however, it was seen as a positive occasion, with the introduction of a 'COVID-19 steering group', highlighting the difficulties that COVID-19 has presented to Antarctic tourism, and how these challenges may be overcome (IAATO, 2020b).

CCAMLR held its yearly meeting online, from the 27th to 30th October 2020 (CCAMLR, 2020b), despite COVID-19. The issues of importance discussed included;

- *'agreed precautionary catch limits for all toothfish fisheries in the Convention Area; significant progress towards a new approach to managing the krill fisheries;*
- *one vessel was added to the Contracting Party IUU-Vessel List; and*

- *two projects approved for funding under its new General Capacity Building Fund and climate change and Marine Protected Areas'* (CCAMLR, 2020b)

Holding meetings online allows for discussions to proceed irrespective of localised issues or conflicts that may obstruct individuals attending meetings in person. The flexibility of Antarctic international meetings allows decisions to continue to be made and makes for more resilience.

Chapter 4: Antarctic Uncertainty in a Risk Society

Section 4.1 Converging Uncertainties

This dissertation aims to answer the question:

> *How do the physical uncertainties associated with Antarctic climate model projections, and Antarctic socio-economic uncertainties combine, to question the credibility, relevance and legitimacy of Antarctic scenarios?*

Having researched Beck's risk society and observing Antarctic physical and socio-economic uncertainties within this context, there are three concluding remarks that deserve mention. The first conclusion is that modelling uncertainty is the dominant source of physical uncertainty for Antarctic surface air temperature projections. Model uncertainty must be minimised by advancing climate models, so policymakers are provided with accurate scientific data to make adaptational decisions. Furthermore, the model uncertainty must be communicated between the science-policy interface, to ensure policymakers do not question temperature projections as credible, relevant and legitimate.

The second concluding remark is that the most critical socio-economic uncertainty impacting the future of the Antarctic is the resilience of the Antarctic Treaty System (ATS).
The third and final conclusion is that climate change is a wicked problem. Within a risk societal lens, and in a world plagued by post-truth politics, the associated challenges of a wicked problem mean that climate change uncertainties are intensified.

The second and third concluding remarks above will be further discussed in this chapter, along with the dashboard presented in Chapter 3 (Table 5) outlining how these can be utilised for further work. The importance of model uncertainty as a physical uncertainty will not be discussed in this Chapter, as it has already been analysed in Chapter 2.

4.1.1 Antarctic Uncertainties and a Risk Society

By evaluating the socio-economic elements and identifying their associated uncertainties in the dashboard (Table 5) total uncertainty, along with scenario uncertainty, can be minimised. Each Antarctic socio-economic element had sperate uncertainties in its trends and developments; however, the Antarctic governance system pervades all Antarctic elements.

Increased threats to the ATS would disrupt all elements and lead to a higher uncertainty within the Antarctic.

Threats to the Antarctic Treaty System

When the ATS was signed in 1959, the political environment was different from now (Bunikowski and Hemmings, 2021; Haward, 2017). One of the Antarctic Treaty's most significant drivers was the discussion of territorial claims on the Antarctic around the Cold War (Rothwell & Hemmings, 2018). With a focus on de-militarisation, the Antarctic continent was where, politically, states could assert dominance. The cold war highlighted what could occur when states became too power-hungry. The Antarctic Treaty was then signed to neither recognise nor dispute any territorial claims previously made on the Antarctic.

The ATS relies on signatories cooperation and compliance (Bunikowski & Hemmings, 2021). As time has progressed from the signing of the Antarctic Treaty, political alignments and priorities have shifted, with many states showing an interest in the Antarctic for economic reasons that might damage the continent environmentally (Walt, 2017; Harvie, 2019). To reflect this, the ATS has expanded to include legislation focused upon issues such as marine harvesting, mineral exploitation and sealing (Bunikowski & Hemmings, 2021).

However, Antarctic governance remains centred around peace and science. Bunikowski and Hemmings (2021) state that 'The ATS is a notionally open access system with a very thick glass ceiling in terms of the technical, scientific, administrative and financial prowess necessary to break through and operate substantially in the Antarctic' (Bunikowski and Hemmings, 2021, p.18). In this view, the ATS is set up, so only a select few states are given the power to negotiate changes or alterations in how business is conducted in the Antarctic. Consultative parties dictate activities within the ATS. It is not easy to become a consultative party (Rothwell & Hemmings, 2018) and the ATS restricts consultative status to countries with enough wealth to participate in Antarctic scientific endeavours.

Science, in Western culture, equates to knowledge and rising power. The involvement of Asian countries in the Antarctic has progressed in recent years (Haward, 2013); however, the ATS heavily reflects a westernised society (Bunikowski & Hemmings, 2021).

Nevertheless, China is an example of a state that is developing into a 'polar great power' (Harvie, 2019a) increasing its scientific presence in Antarctica, exhibited by its growing number of research stations. Professor Anne-Marie Brady has discussed China's involvement in the Antarctic and that their increasing interest in military activity and mineral exploitation is increasing the pressure on the ATS (Harvie, 2019b). Antarctica's size and lack of territorial claims have turned it into a political asset, with the potential for conflict regarding which superpower states have the most control over Antarctica's economic assets.

In 1959, the 12 original signatories to the Antarctic Treaty all had aligned priorities, with the distinction between military and civilian extremely clear (Bunikowski and Hemmings, 2021). Nowadays, the lines separating Antarctic military and civilian roles are blurred, with cooperation occurring for transportation, communication, or access to technology and facilities. With increased membership and heightened military presence in the Antarctic, there is rising Western anxiety surrounding the change in states' priorities and capabilities concerning Antarctic engagement (Bunikowski and Hemmings, 2021). Currently, there is not enough imbalance of power or political tension to break ATS agreements. However, as politics evolve and priorities of power or wealth increase, Antarctic exploitation could occur. The ATS includes language and assumptions about the political and social world that are not relevant to today's Antarctic activities, which raises significant uncertainty with how the ATS will respond to global conflict and whether its framework is resilient enough to handle too much global change or political pressure (Walt, 2017).

The ATS impacts all socio-economic elements in Antarctica, and therefore, questions regarding it's resilience significantly raise the level of uncertainties.

<u>Risk Society</u>

This dissertation concludes that the major concepts introduced in this study combine to create a challenging space for the public to accept climate change, which in turn creates impediments to exploring ways to overcome it. Climate change as a wicked problem is difficult for policy to overcome (Camillus, 2008). A risk society places pressure on governments to act and provide solutions for wicked problems; however, the presence of post-truth politics within a risk society provides politicians with potential excuses from being held accountable for making little progress.

Instead of proposing new ideas or admitting partial defeat in solving climate change, post-truth politics allows politicians to undermine the credibility of climate change, therefore disputing the need to take political action (Bufacchi, 2020). In a world of a risk society, there is less trust surrounding scientific institutions and organisations, giving leaders such as Donald trump the ability to appeal to the public's general mistrust, denying climate change altogether (Spoelstra, 2020). A risk society provides governments and leaders with the perfect opportunity to appeal to the public's mistrust and avoid finding a solution to a problem deemed too challenging to tackle.

As previously explained, the most significant uncertainty within the Antarctic continent is the ATS's future, and this uncertainty is magnified within the world of a risk society. The politics of a risk society may place more pressure on individual signatories to the ATS because of domestic priorities, which could question the ATS's ability to maintain control and regulate Antarctic activities. Tensions could occur between significant signatories of the ATS. With the Antarctic governance structure relying on signatories' cooperation, the ATS's ability to deal with international conflict could be tested, particularly dealing with differing views in bioprospecting and mineral exploitation.

Climate change is a wicked problem that will affect the globe but can drastically change the future of Antarctica. If Antarctica is to be protected from future environmental degradation, then any uncertainties that could lead to facts being misconstrued must be minimised. The minimisation of uncertainties within Antarctic future studies and climate modelling will allow these tools to be more credible, relevant and legitimate.

Section 4.2 Final Conclusions

4.2.1 Antarctic Dashboard and Limitations

The research conducted in this dissertation was cross-disciplinary. Modelling was completed to identify the significance of scenario uncertainty, model uncertainty, and natural variability on the Antarctic's temperature projections using the most recent CMIP6 models. Research also analysed and identified uncertainties present within the Antarctic socio-economic space.

This study aims to provide a comprehensive overview of all the physical and socio-economic topics frequently discussed in Antarctic futures work. Thus, this study has various limitations that may have been minimised if the research focused on a singular topic.

Modelling

Only 19 models were used for the global temperature uncertainty projections and 18 for the Antarctic and Arctic temperature uncertainties projections.
If this work were a model-based study, with a more specific focus on the uncertainties in climate models alone, then it would be recommended that a larger dataset, all the CMIP6 models available, would be used for the globe and Antarctic temperature uncertainty modelling.

Furthermore, only one realisation from each of these 19 models was used for this dissertation's temperature uncertainties portion. If this study were to be further developed, it would be appropriate to use as many realisations that CMIP6 models produce to allow for a greater sample set and, subsequently, results representing the uncertainty of all CMIP6 models and realisations.

Using only one realisation and only 19 models may have limited the accuracy of the results in this study, as it is not representative of all CMIP6 data. However, due to this experiment using 19 CMIP6 models, the smaller dataset is not likely to have skewed results considerably. It is considered that the major trends observed would be similar to those observed if a more extensive dataset was used.

When referring to this dissertation's socio-economic portion, the research completed also contains several limitations that could be refined if the study was not cross-disciplinary.

Each socio-economic element was researched to provide background on its definition and past trends. This research was done using a variety of online sources and peer-reviewed papers. However, to develop this research further, it would be advised that more time be spent on each element, with more extensive databases analysed. Contacting ATS representatives or researchers that have relevance to the element in question are ways that research into socio-economic elements could be further refined.

Furthermore, once this data had been acquired, trends could be mathematically analysed and graphically displayed, such that readers have a greater understanding of any patterns present within the data.

The dashboard presented in this study aimed to cover the most significant uncertainties; however, a potential weakness is its ability to capture more minor uncertainties. Given more research time and capabilities, this dashboard could be advanced and expanded to include more minor Antarctic uncertainties.

The dashboard was created from Frame's (2020a) Antarctic socio-economic dashboard, representing the elements that will impact the Antarctic's future. However, this dashboard was made subjectively, with no set regulations defining what elements should be included. Subsequently, a further limitation is that readers may disagree with the elements and uncertainties included within the dashboard.

4.2.2 Future Work

This dissertation aims to complete the first two steps within the DAPP process, identifying and addressing the uncertainties within the Antarctic, providing more informed policy advice. When new Antarctic scenarios are made, researchers will now have a more comprehensive understanding of Antarctic uncertainties. These will help guide the decisions made surrounding the future of the Antarctic.

When creating future scenarios for Antarctica, the dashboard's uncertainties can be explored for their many potential pathways and outcomes. Due to the conclusion that governance is the most crucial uncertainty for Antarctica's future climate, this uncertainty should be investigated the most. Different pathways of the future of Antarctic governance and the ATS should be projected, allowing future scenarios to incorporate various outcomes, rather than limiting the flexibility of the scenarios by assuming Antarctic governance will develop in a single path. Furthermore, once Antarctic governance is explored for its potential outcomes, researchers should investigate how these different governance pathways will subsequently affect other socio-economic elements.

This outlook can identify what may need to be altered or changed within the ATS to appropriately deal with changing environments and society.

This dissertation has identified what sources of modelling uncertainties can be minimised. For future work, more time could be placed into developing modelling structures, placing more resources into creating a better understanding of the climate system and Antarctic climate feedback loops. This will minimise model uncertainty, and allow for more appropriate policy decisions to be made about Antarctica specifically.

Analysing Antarctic uncertainties presented in this dashboard is a way of delving into imminent threats to Antarctica’s future. However, unless political action is taken as a response to the findings of this research, then climate change, and its subsequent negative affect on Antarctica, will continue. Futures studies explore potential pathways and outcomes for the globe or region, but these don’t necessarily lead to direct or mandatory policy changes. There is no correct approach to solve a wicked problem. Although using projections of potential future climate outcomes can clarify what the future may look like, it does not mean social or environmental changes will occur. This requires political action.

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Appendix 1

Tables and Supplementary Information

Table 1 Summary of Shared Societal Pathways derived from descriptions by O'Neill et al., (2017)

Shared Socioeconomic Pathway	Description
SSP1: Sustainability—Taking the green road	Most sustainable path, greater management of global commons, leading to a greater collaboration of local and global institutions. Heath and education investments rise, with inequality lowered. Greater resource efficiency with a rise in technological advancements, reducing energy use. Renewable energy favoured with financial incentives, with consumption being focused around lower resource and energy intensity. Combinations of these factors return **low challenges to mitigation and adaptation.**
SSP2: Middle of the road	Global sustainability development is worked towards, but progress is slow. Environment degrades, however overall energy use is lowered. There is no preference for renewable energy. Social, economic and technological trends similar to the present. Global population grows moderately, then plateaus after approximately 2050. There is no investment in fertility education in lower socio-economic societies, creating an increasing inequality gap with a growth in population in low-income nations. Social cohesion is low, with social and environmental challenges prevalent. This SSP faces **moderate challenges to mitigation and adaptation.**
SSP3: Regional rivalry—A rocky road	Some strong regional environmental degradation, with low international investment in environmental issues. Domestic and regional issues are prioritised; with a low level of global cooperation. Barriers are introduced for trading, with a policy focus on national security. Investments in technology and education decline, with material consumption prominent. Inequalities, especially in lower socio-economic regions escalate. Poor progress towards sustainability with a decrease in environmental investment and an increase in inequality.

	Developing countries exhibit high population growth, whilst developed countries populations are stable. Fossil fuel dependency is high, causing **high challenges to mitigation and high challenges to adaptation.**
SSP4: Inequality—A road divided	Global and regional inequlity is high. Society is split into ‘an internationally-connected society that is well educated and contributes to knowledge- and capital-intensive sectors of the global economy, and a fragmented collection of lower-income, poorly educated societies that work in a labour-intensive, low- tech economy’ (O’Neill et al., 2017, p. 173). Vulnerable groups have little democratic voice, with political power lying in the higher socio-economic sectors. There is high technological development within higher-tech economies and underinvestment in new resources in certain regions. Energy companies disperse their sources from traditional fossil fuel sources, to low-carbon alternatives. The environmental focus is on higher class local and regional issues. A combination of the application of some low-carbon fuel sources, as well as there being a well functioning higher part of society forces **low challenges to mitigation and high challenges to adaptation.**
SSP5: Fossil-fueled development—Taking the highway	Increased faith in competitive markets comes with the economic growth produced by industrialisation and the development of human capital. Global markets are integrated, with strong investments in health, and education. Economic and social development is fuelled by carbon resources, with overall rapid growth. Local environmental issues are addressed with technological advancements, however, there is little global effort to minimise emissions due to the tradeoff of a flourishing economy. High fossil fuel usage, coupled with a low concern for global emission rates lead to **high challenges to mitigation and low challenges to adaptation.**

Table 2 Categories and Elements copied from O'Neill et al. (2017) involved in climate change scenario making (Source: O'Neill et al. 2017, p.396)

Category	Elements for global climate change scenarios
Demographics	Population total and age structure
	Urban vs rural populations, and urban forms
	Other location information, such as coastal vs inland
Economic development	Global and regional GDP or trends in productivity
	Regional, national, and sub-national distribution of GDP, including economic catch-up by developing countries
	Sectoral structure of national economies, in particular the share of agriculture, and agricultural land productivity
	Share of population in extreme poverty
	Nature of international trade
Welfare	Human development
	Educational attainment
	Health, including access to public health and health care infrastructure
Environmental and ecological factors	Air, water, soil quality
	Ecosystem functioning
Resources	Fossil fuel resources and renewable energy potentials
	Other key resources, such as phosphates, freshwater, etc.
Institutions and governance	Existence, type and effectiveness of national/regional/global institutions
	Degree of participation
	Rule of law
Technological development	Type (e.g. slow, rapid, transformational) and direction (e.g. environmental, efficiency, productivity-improving) of technological progress

	Diffusion of innovation in particular sectors (e.g. energy supply, distribution and demand, industry, transport, agriculture)
Broader societal factors	Attitudes to environment/sustainability/equity, and world views
	Lifestyles (including diets)
	Societal tension and conflict levels
Policies	Non-climate policies including development policies, technology policies, urban planning and transportation policies, energy security policies, and environmental policies to protect air, soil and water quality. It is possible that SSPs could be specified partly in terms of policy objectives, such as strong welfare-improving goals, rather than specific policy targets or measures.

Table 3 Copy of Antarctic Scenario Dashboard from Frame (2020a), derived from O'Neill et al. (2017) Global Elements.

Category	Element	Indicator	
1 **Direct Human Impact**	*Research community and support*	1.1	Research Activity: Number of researcher person-days per annum and logistics support (transport, supplies, energy and so on)
		1.2	Research Spend: Total global value accommodating inflation projections
	Physical impact of research community	1.3	Infrastructure: Numbers of stations, field-camps, etc.
		1.4	GHG footprint
		1.5	Environmental impact data
		1.6	Accidents: Days lost and potential impacts (e.g. reverse zoonosis)
		1.7	Search and Rescue: Incident numbers
2 **Economic Impact**	*Fisheries*	2.1	Presence: Number of vessels operating in Southern Ocean
		2.2	Yield: Volume and economic value per annum
	Tourism	2.3	Presence: Number of vessels, passengers and crew in Southern Ocean
		2.4	Yield: Volume and economic value per annum
		2.5	Accidents: Incident Numbers
	Bioprospecting	2.6	Harvesting: yields, operators, vessels, etc. *(Currently zero)*
		2.7	Yield: Patents applied for and issued. Volume and economic value per annum
3 **Ecological and Environmental Processes**	*Physical Environment*	3.1	Global air temperature
		3.2	Antarctic air temperature
	Oceanographical processes	3.3	Antarctic contribution to sea level
		3.4	Southern Ocean temperature
		3.5	Summer sea ice extent
		3.6	Ice shelf volume
	Ecological processes	3.7	Red List criteria. Indicators of species numbers, health and viability. Strategic goals
		3.8	Measures of ecosystem services
	Biological Invasions of Non Native Species	3.9	Numbers of non-native species identified and indicator of their voracity. Viability of BNNJ and relationship with IPBES (or successor)
		3.10	Monitoring and assessment of control measures in place and their effectiveness
4 **Resources exploitation**	*Minerals extraction*	4.1	Status of ban on all aspects of mining
		4.2	Yield: Volume and economic value per annum (if 4.1 is not zero)
5 **Governance**	*Processes & participation*	5.1	Organisational monitoring and evaluation indicators of performance
		5.2	Integration of ATCM, CCAMLR, COMNAP, SCAR processes and strategic plans to achieve long-term goals with intermediate success criteria
	Impact	5.3	Effective protection by MPAs, ASPAs, ASMAs and HSMs
		5.4	Interactions between ATCM, CCAMLR, the UN system and multilateral agencies, e.g. IAATO, IMO, IPBES, and IPCC
6 **Technological Development**	*Research priorities*	6.1	Summary of long-term SCAR vision & strategy science priorities. National research strategies
		6.2	Total economic value of all science programmes in Antarctica
	Geoengineering	6.3	Description of current and proposed geoengineering relating to Antarctica
		6.4	Total economic value of Antarctic specific geoengineering programmes (if any)
7 **Broader societal factors**	*Role of science in society*	7.1	Importance of polar science in ATS members national policies, namely the impact of Antarctic science in terms of supporting Antarctic governance and broader global issues
		7.2	Role of science in the societies of the ATS member nations
	Dominant environment values	7.3	Description of how geographical perspectives of Antarctica are developing. Presence and content of Antarctica in social sciences and humanities
		7.4	Description of environmental issues globally such as attitudes to climate change
	Arts, heritage & the media	7.5	Description of cultural heritage including reports to ATCMs, changes to HSMs
		7.6	Description of impact of Antarctica outside the research world and its impact. Presence of Antarctica in arts and the media

Table 4 List of CMIP6 Models used to Project Surface Air Temperature for the Globe, Antarctic and Arctic

Model Name	**Reference**
ACCESS-CM2	(Dix et al., 2019)
ACCESS-ESM1-5	(Ziehn et al., 2019)
BCCCSM2-MR	(Wu et al., 2019)
CanESM5	(Neil Cameron Swart et al., 2019)
CESM2-WACCM	(Danabasoglu, 2019)
CNRM-CM6-1	(Voldoire, 2019)
CNRM-ESM2-1	(Seferian, 2019)
FGOALS-f3-L	(YU, 2018)
FGOALS-g3	(Li, 2019)
GFDL-ESM4	(Horowitz et al., 2018)
GISS-E2-1-G	((NASA/GISS), 2019)
INM-CM4-8	(Volodin et al., 2019a)
INM-CM5-0	(Volodin et al., 2019b)
IPSL-CM6A-LR	(Boucher et al., 2020)
MCM-UA-1-0	(Stouffer, 2019)
MIROC6	(Takemura, 2019)
MPI-ESM1-2-LR	(Brovkin et al., 2019)
NorESM2-MM	(Bentsen et al., 2019)
UKESM1-0-LL	(O’Connor, 2019)

Table 5 Dashboard of Socio-economic elements effecting the future of the Antarctic, and their associated uncertainties. Refined from Frame's (2020) Antarctic elements.

Category	Socioeconomic Element Impacting Future Antarctic scenarios	Indicators	Associated Uncertainties
1. Institutions and Governance	1.1 Antarctic Governance	1.1a CCAMLR 1.1b Madrid Protocol	• Success of ATS • Changing priorities of signatory states • Ability to prevail as the governing piece of legislation in a changing world
2. Economic Impact	2.1 Bioprospecting		• Success of ATS
	2.2 Fisheries		• Catch estimates • Ecosystem knowledge (population, life cycle) • Species response to change • Success of ATS
	2.3 Tourism		• Number of tourists (Global financial crisis, COVID-19) • Tourism transportation • Tourism safety (accidents, e.g. Erebus disaster) • Success of ATS
3. Direct Human Impact	3.1 Research community		• Environmental Impacts of Research Stations and Transportation • Research Accidents (Mistakes, Human Error)
	3.2 Physical impact	3.2a Search and Rescue	• Accidents (Human Error, Weather Events, Unprecedented Incidents) • The success of the ATS (Ensure Effective Communication between RCC)
		3.2b Microplastics and Carbon Footprint	• Accidental Contamination (Human Error, weather), • Emerging Technology • The success of ATS (environmental protection priorities)
		3.2c Wildlife	• Accidental spills (human error) • Wildlife's ability to rebound • Success of ATS
4. Ecological and Environmental Processes	4.1 Physical environment	4.1a Temperature Observations and Predictions 4.1b Oceanographic 4.1c Cryosphere	• Modelling uncertainties • Individual and combined country response to climate change • Success of ATS
	4.2 Ecological processes		• Future tourism trends • Future climate change • Success of ATS
	4.3 Biological invasions of Non-Native Species		• Future tourism trends • Success of ATS
5. Resources exploitation	5.1 Minerals extraction		• Emerging technology • Success of ATS
6. Technological Development	6.1 Research priorities in the Antarctic		• Changing research priorities • Changes in funding allocation
	6.2 Geoengineering		• Priorities of governments and National Antarctic Programmes
7. Broader societal factors	7.1 Dominant global attitudes to the environment		• Priorities of signatory states • Success of ATS
	7.2 COVID-19		• ATS Meetings • Antarctic research • Virus outbreak • Antarctic tourism

Appendix 2

Antarctic Protected Areas

Each annexe of the Protocol was agreed upon by consultative parties at ATCMs before it could be signed and implemented.
These protected spaces include; Antarctic Specially Protected Areas (ASPA), Antarctic Specially Managed Areas (ASMAs), Historic Sites and Monuments (HSMs), and Marine Protected Areas (MPAs).
All-natural resources are protected within an MPA. It differs from the other three protected spaces as the area in which it occupies merely is marine. CCAMLR proposes MPAs, to then be analysed by CCAMLR's Scientific Committee and Commission. MPA's limit activities in the region and place strict guidelines regarding what interactions within MPA's are allowed (CCAMLR, 2020a).

Within ANNEX V of the Madrid Protocol, Antarctic Specially Protected Areas (ASPA) and Antarctic Specially Managed Areas (ASMA) were drafted, to further outline what activities were inappropriate in specific areas on the continent. As technology advanced, and as time increased, the ANNEX's were signed to allow the Antarctic Treaty to move with and developing changes in the world. As more previously inaccessible parts of Antarctica were opened to exploration (transportation and weather gear improving), legislation was required to outline dos and don'ts; upholding the Antarctic Treaty goals at preserving Antarctica for peace and science. Article 3 of ANNEX V states that 'any area, including any marine area, may be designated as an ASPA to protect outstanding environmental, scientific, historic, aesthetic or wilderness values, any combination of those values, or ongoing or planned scientific research' (ANNEX V: Area Protection and Management, 2002). ASPA's are areas unable to visit unless the party has a designated permit. Article 4 of ANNEX V states that' any area, including any marine area, where activities are being conducted or may in the future be conducted, may be designated as an ASMA to assist in the planning and coordination of activities, avoid possible conflicts, improve cooperation between Parties or minimise environmental impacts' (ANNEX V: Area Protection and Management, 2002). ASMA's are different from ASPA's, where they impose a management plan. ASPA's however, can be contained within ASMA's, and therefore particular regions of ASMA's also may be off-limits without a permit.

Further, in ANNEX V, article 8 outlines historic sites and monuments. HSMs are sites recognised by states as ones that hold particular historical value and cannot be removed or damaged. All ASPAs, ASMAs and HSMs are proposed by a state or party, as they believe the site or area lies beneath the rules required for them to be protected or managed accordingly. These proposals are held before the Antarctic Treaty consultative parties at ATCMs. They are then voted upon to determine the proposal's validity (ANNEX V: Area Protection and Management, 2002).

Fisheries Data

Toothfish

A delicacy in many countries; the Antarctic toothfish is a prized fish currently caught by 13 licensed fisheries. Toothfish generally are caught using longlines but can also be fished using trawl and pot. Two species; *Dissostichus Mawsoni* and *Dissostichus Eleginoides*, are fished in the Antarctic waters. *Dissostichus Eleginoides* have catches between 10000-15000 tonnes per year, and their catch number has remained relatively constant for the past 20 years. *Dissostichus Mawsoni* began to be fished in 1998 and brings in catches between approximately 3000-5000 tonnes per year (CCAMLR, 2019).

Icefish

Icefish were heavily fished in the Southern Ocean during the 1970s and 1980s. This overfishing lead to decreased supply, resulting in the closure of Icefish fisheries in the 1990s. Since their closure, catches of Icefish have become small, to non-existent, with any catches in a year bringing in either no stock or less than 500 tonnes (CCAMLR, 2019).

Krill

Antarctic krill is caught by use of midwater trawls and beam trawls. Catch numbers of Antarctic Krill peaked to 400000-450000 tonnes per year during the late 1970s-early 1990s. This number decreased to approximately 10000 tonnes per year in the mid-1990s. Antarctic Krill catches have steadily increased to approximately 300000 tonnes in 2018 (CCAMLR, 2019).

Antarctic krill is a keystone species, as it is a significant part of many species diets; one towards the bottom of the food chain. For this reason, its fishery data must be monitored and regulated by CCAMLR not to overfish the species. 'CCAMLR's approach to managing the krill fishery is to minimise the impact on the ecosystem rather than trying to maximise the size of the fishery' (CCAMLR, 2019). Simulations are performed to estimate the krill population's productivity and numbers, with an annual catch size of 620000 tonnes in the Southwest Atlantic. This number represents 1% of the overall krill size (unexploited) within this region (CCAMLR, 2019).

Antarctic Whaling

Whaling was banned by the International Whaling Commission (IWC) in Antarctica in 1986 (ASOC, 2020). This ban set catch limits of zero across all whale species within the Antarctic. Before this ban, whaling significantly affected Antarctica's wildlife, impacting all Southern Ocean whale species, with population numbers heavily depleted. The 1986 ban on whaling in the Antarctic was further advanced by introducing the Southern Ocean Whale Sanctuary (SOWS) in 1994, covering the summer feeding regions for 80-90% of the globes whales (ASOC, 2020). Japan continued to whale within the Southern Ocean under scientific research permits; however, this was later halted in 2014 due to Australia's proposal to end all whaling in Antarctic waters, scientific and commercially (ASOC, 2020).

There are multiple uncertainties within the socio-economic element of *direct human impact* and how this affects Antarctic wildlife. As a result of tourism, the impact that humans have directly on the wildlife is monitored by IAATO, but can also involve uncertainties depending on the situation; relying on individual tourists' compliance and the cooperation of tourism staff.

Accidental spills of oils or waste can impact surrounding wildlife from scientific research stations within the Antarctic. This uncertainty results from human error, or the inability to maintain research stations to be less harmful to surrounding ecosystems.

The adverse effects of overfishing in Antarctic waters relies on monitoring by CCAMLR and intervention by ATS parties. Uncertainties of incorrect population estimates, due to illegal fishing and lack of information on a species, can increase these adverse effects, and result in the unsustainable fishing industry.

The significant uncertainty underlying the adverse effects that human impact has on Antarctic wildlife is the success of the ATS. IAATO, CCAMLR and RCC's are either organisations that are a subset of the ATS or were formed due to its signing.

Uncertainties surrounding the future of Antarctic governance would heavily impact future monitoring and regulation of direct human impact on the Antarctic wildlife and ecosystem.